Structural Design of Buildings: Fundamentals in Design, Management and Sustainability

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Structural Design of Buildings: Fundamentals in Design, Management and Sustainability

Feng Fu and David Richardson

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Foreword

Structural engineering is a complex discipline combining science and creativity to develop our built environment and to provide structures that benefit society. As structural engineers, we regularly consider complex problems or challenges and use our skill and training along with an understanding of physics and mathematics to find safe, elegant, buildable solutions.

Structural engineers have a responsibility to protect public safety and, as key players in building and infrastructure design, assist in facilitating the vision of architects, developers, governments, private organisations and individual end users.

In a world with widespread realisation of the Earth's finite resources, combined with the devastating affect that the construction of our built environment is having on the planet's climate and biodiversity, civil and structural engineers practising today have a responsibility to balance the increasing needs of the world's growing population while reducing demand on natural resources. The impact of our actions when creating and maintaining the built environment is rightly at the fore.

As Planet Earth becomes more crowded, increasingly dense populations are subjected to higher risks resulting from any failings within the structures in which they live, work and play. Fire, earthquake, extreme weather, explosion, physical damage and structural neglect are all factors that can, and do, cause buildings and structures to collapse, with devastating consequences. As engineers, it is critical that we fully consider these risks and ensure that our buildings and structures can continue to perform safely under extreme events to protect human life.

It is imperative that structural engineers continue to develop themselves with up-to-date knowledge and best practice throughout the whole of their careers.

Emerald Publishing has drawn together leading experts in the field of structural engineering to write about the fundamentals, materials, processes and generic principles of structural design.

Edited by Professor Feng Fu and Professor David Richardson, each chapter is written by a different expert author and carries its own style and themes. The complete guide covers a wide breadth of structural engineering topics and is split over three books covering: the fundamentals of design, procurement and sustainability, guidance on structural consideration of the major construction materials, and holistic design approaches. This guide provides a valuable overview and source of information for engineers, in helping to ensure their continued competence and understanding of this wide ranging and very rewarding discipline.

A closing thought … ‘engineer’ is a word derived from the Latin ‘ingeniare’ meaning to contrive or devise. It is also related to ‘ingenious’ (of a person) clever, original and inventive. In summary, engineers are inventive problem solvers! Let us therefore work together, as a profession, to share knowledge and best practice and make the built environment better, cleaner, safer and more environmentally responsible.

EUR ING Matthew Byatt CEng FIStructE
102nd President of The Institution of Structural Engineers

Preface

The *Structural Design of Buildings* series provides an authoritative introduction to the core knowledge for structural engineers to design a building. This series provides a comprehensive reference on structural design for practising engineers, university students of civil and structural engineering, and stakeholders such as developers, architects, surveyors and other non-experts in structural design who require reference information for designing a building.

The *Structural Design of Buildings* series provides timely updates of the advances in structural design principles for modern buildings. The series takes a project-oriented approach, covering the necessary topics that design professionals face at the outset, and throughout the duration, of a project. It presents the key issues needed to grasp a subject quickly and effectively, as well as providing the necessary tools for building design practice. The contributors of each chapter are proven experts from different countries across the world and are leading figures in their subject area, reflecting the best of current practice globally.

The series stems from the *ICE Manual of Structural Design of Buildings*. Rather than update the manual as a whole, it has been split into a series to provide an opportunity for those interested in part of the content to purchase the sections that are relevant for their purposes. The series is comprised of three books

- *Structural Design of Buildings: Fundamentals in Design, Management and Sustainability*
- *Structural Design of Buildings: Elemental Design*
- *Structural Design of Buildings: Holistic Design.*

The range of topics in the series provides comprehensive key knowledge required in structural design, technological advances and best practice for readers.

Acknowledgements

In the process of preparing this series, we have been extremely fortunate in being helped and guided by many people. We would like to thank Viktoria Hartl-Vida and Cathy Sellars (the Editors at Emerald Publishing), together with their colleagues for their expert assistance with reviewing material. We acknowledge the contributions of all chapter authors and thank them for their diligence and hard work. Finally, thank you to those parties who granted the copyright of the figures and charts used in this series.

The Editors would like to thank the following authors who contributed to The *Structural Design of Buildings* series

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Salam Al-Bizri
Ashraf Ashour
Meike Borchers
Owen Brooker
Bernardino D'Amico
Peter Debney
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Alex Hu
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Feng Fu is a Chartered Structural Engineer, Fellow of the Institution of Structural Engineers, Fellow of the American Society of Civil Engineering and Fellow of the Institution of Civil Engineers. He was a council member of Institution of Structural Engineers (IStructE) in 2020 and Chair for the North Thames Regional Group of IStructE in 2020. He is a Editor-in-Chief of *Proceedings of the Institution of Civil Engineers – Structures and Buildings*, an Associate Editor of the *Journal of Structural Engineering*, American Society of Civil Engineers, and Associate Editor of the *Journal of Performance of Constructed Facilities*, American Society of Civil Engineers (ASCE). He is consecutively listed in Stanford's top 2% of scientists in the world. He has contributed to the formulation of two design codes by the American Society of Civil Engineers: '*ASCE/SEI 59-22 Blast Protection of Buildings*' and '*ASCE 76-23 Standard for Mitigation of Disproportionate Collapse Potential in Buildings and Other Structures*'.

He has been working as a faculty member for City, University of London and University of Bradford since 2010. He was Changbai Mountain Distinguisher Visiting Professor in Jilin Jianzhu University and Distinguished Visiting Professor in Guilin University of Technology in China. Prior to joining academia, he worked for several world leading engineering consultancy companies and has worked on extensive prestigious construction projects worldwide, including over 20 tall buildings (most of buildings over 200 m), such as the tallest building in western Europe, the Shard in London; Nido Tower in London (the third tallest student dormitory in the world); Nakheel Tower in Dubai (1000 m tall, scheme design, the tallest (proposed) building in the world); 22 Bishopsgate (the second tallest building in London, participated in the first stage design before 2008); Beijing WangZuo Centre; Beijing Yuanyang complex; and Beijing Kerry Centre. He was also the team member of several large-scale complexes, such as the award-winning Bristol Broadmead Shopping Centre, Heathrow Airport T2 and Qin Huang Dao stadium. He has also participated in the design of bridges, long-span structures, hospitals, and almost all types of structures.

David Richardson BEng(Hons), CEng, FIStructE, FHEA

David Richardson is a Chartered Structural Engineer and Associate Professor of Structural Design in the School of Civil Engineering at the University of Leeds, UK. He is currently Structural Design Champion and accreditation lead in the school. David is also a Fellow of the Institution of Structural Engineers (IStructE) and past Chair of the

IStructE Yorkshire Region. For 27 years prior to becoming an academic, David worked in industry as a Consulting Structural Engineer, the final six years of which was spent as a Technical Director in the WYG group. David has a track record of successfully leading the Civil and Structural design of projects in a variety of sectors including healthcare, education, leisure, research and stadia. Major projects delivered by David whilst working in industry include the £500m Queen Elizabeth Hospital, Birmingham, the £300m Pinderfields and Pontefract Hospital, Wakefield, and the £145m Target Station 2 spallation neutron source at Rutherford Appleton Laboratory, Oxford.

About the contributors

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Dr Sepehr Abrishami is a distinguished Senior Lecturer and course leader for the MSc BIM programme at the University of Portsmouth. With a rich background in architecture and an extensive research portfolio, his expertise spans multiple continents, including Europe and the Middle East. As a seasoned architect and visionary researcher, Dr Abrishami has made remarkable contributions to the fields of architecture, integrated and digital design, and constructionism. He is a pioneer in the application of cutting-edge technologies such as artificial intelligence, blockchain, virtual/augmented/mixed reality programming for the automation and simulation of design, as well as offsite-manufactured construction and virtual prototyping. Dr Abrishami's journey began in Iran, where he earned the prestigious title of First Class Registered Architect. It was here that he initiated his international career by establishing the AA Design Studio. Throughout his career, he has successfully executed a plethora of architectural and interior design projects, receiving acclaim for his work on hotels, residential complexes and more. For over a decade, Dr Abrishami has been at the forefront of IT-integrated architectural design and automation in construction, a journey that began with his Master's degree in Environmental Design at the Welsh School of Architecture, Cardiff University.

Salam Al-Bizri

Salam Al-Bizri has more than 30 years of experience in the higher education sector and the construction industry. Salam is now a Senior Lecturer at the University of Portsmouth. Her teaching interests are construction project management, technology clusters, design management and supply chain management. With input from leading organisations in the field, Salam developed several courses and lectures and sourced and developed site-based case studies. She has been exploring issues surrounding the integration of design and construction processes and how, through education, a better understanding of the industry can be achieved and best practices delivered. By acquiring and exploiting the knowledge and skills of experts in the field, students can be educated in the cause-and-effect relationships resulting from decision-making. This is demonstrated as best practice as well as illustrating the weaknesses in how activities are currently carried out and challenging students to question the common management approaches.

Meike Borchers

Meike Borchers is a Sustainability/ESG Specialist and Project Manager with over 20 years of experience in the built environment and has worked in Germany, the UK, the USA and Sweden. She has been involved in a wide range of projects focusing on sustainability in building design including performance analysis, energy efficient technologies, climate change adaptation of buildings, healthy and sustainable materials selection and procurement, Passivhaus design and environmental lifecycle analysis. Her international project experience primarily covers real estate in Germany, the UK, the USA but also the Middle East and Africa, ranging from new construction to refurbishment. This includes advising clients on designing, constructing and running environmentally conscious but also healthy and stimulating buildings with a focus on materials, performance monitoring and certification. She is an experienced BREEAM AP, LEED AP, WELL AP, Fitwel Ambassador and Certified Passivhaus Designer. She has guest lectured at UCL's Bartlett, teaching MSc students on methods for the environmental performance assessment of buildings.

Peter Debney

Peter Debney is a Chartered Engineer, a Fellow of the Institution of Structural Engineers and is the author of *Computational Engineering* (Debney, 2020) and numerous other book chapters and papers. He graduated with honours in a Bachelor of Engineering Civil Engineering degree from the University of Surrey and has a Computing Diploma from the Open University. He is a member of the Institution of Structural Engineers Digital Workflows and Computational Design panel and is a visiting expert on finite element analysis with CROSS-UK. Over his career he has worked for a water authority, contractors and consultants, working on projects ranging from house refurbishments to major industrial facilities, both as a structural engineer and a CAD technician. He has also worked for engineering software companies as a product manager, business development manager and application specialist. He has been a Royal Academy of Engineering Visiting Professor at Bradford University for structural design and finite element analysis and is a regular guest lecturer at several other universities. He works for Arup as the Customer Service Lead and Quality Systems Manager in the Digital Technology department (Oasys Software, 2023).

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Ravindra Kumar Dhir is an award-winning academic who enjoys both teaching and research in the area of concrete science and technology, with each enhancing the other and closely interacting with the industry. Ravindra's hallmark is developing the world class Concrete Technology Unit (CTU), working in close collaboration with the concrete and construction industry, with state-of-art research facilities and disseminating the new knowledge globally. This won him numerous national and international honours and awards including his national honour from Queen Elizabeth II in 1989. He graduated from the universities of Durham (King's College) and Sheffield and works with the universities of Dundee, Dublin (Trinity College) and Birmingham. He is resolute in what he does, has produced over 450 imaginative publications, including several award-winning ones, and has travelled globally in connection with his work.

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Chao Qun Lye, a graduate of the National University of Singapore, earned a Doctor of Philosophy degree in Civil Engineering from the University of Birmingham. With many years of experience in the ready-mix concrete industry, he possesses a strong interest in sustainability and innovation. Currently, he is conducting research at the National University of Singapore, focusing on the use of recycled and waste materials in cement and concrete applications. Additionally, he has authored several books and papers published in peer-reviewed international journals. Two of his publications were honoured with the Magazine of Concrete Research Prize in 2016 and 2022 by the Institution of Civil Engineers in the UK.

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Elisabeth Marlow

Elisabeth Marlow, a Chartered Structural Engineer, brings over two decades of international experience in sustainability consultancy. Her expertise spans a spectrum of decision-making processes, ranging from organisational strategies to large-scale urban projects. Her primary focus is on aligning project objectives to foster greater resilience and adaptation responses to natural hazards, considered net zero carbon pathways and green building strategies. Her academic journey includes completing her Doctoral Research at Loughborough University, where she delved into the intricate interplay between sustainability and resilience in the built environment. This research provides a foundation for practical applications in her role as a Principal Consultant, where she actively works on projects that prioritise sustainability and resilience. She is as an award-winning engineer and holds the prestigious title of Fellow of the Institution of Structural Engineers, acknowledging her significant achievements in the field.

RB Marshall

RB Marshall is Head of Engineering for THE LINE in NEOM, located in the Kingdom of Saudi Arabia. THE LINE is the largest construction project in history and consists of a linear mirrored city 500 m tall and 170 km long. Prior to joining NEOM Richard was a Partner at Buro Happold where he headed the tall buildings and seismic global expert communities and worked on projects including the Chicago Spire, the Museum of the Future in Dubai, the Louvre Museum in Abu Dhabi, the Mercedes Benz Stadium in Atlanta, the Changi Jewel in Singapore, the ExCeL centre in London as well as dozens of tall building projects of up to 2000 m in height on every continent. From New Zealand, Richard attended Canterbury University in Christchurch and graduated as a Civil Engineer. Prior to joining Buro Happold in 1997 he worked in New Zealand and South East Asia, starting from when he left school in 1987.

Fred Veer

Fred Veer studied materials science at Delft University of Technology, graduating with an MSc in Engineering in 1988. He went on to research fatigue of metals for his PhD in 1993. In 1994 he was appointed Assistant Professor of Materials Science in the Architecture faculty of Delft University of Technology and was promoted to Associate Professor in 2007. His specialities include teaching materials selection and researching the statistics of glass failure. He is the (co-)author of over 40 refereed papers on glass design and glass strength and of some 40 papers on other topics.

Saeed Ziaie

Saeed is a Director and Head of Engineering Integration with WSP with responsibility to drive to achieve right and balanced engineering solutions and technical assurance. Saeed is a chartered engineer with 35 years of experience in the design and construction of civil and structural engineering projects in the UK and internationally. Saeed's experience comes from working on a variety of projects, including major infrastructure projects, for both public and private sectors and covers assessment, feasibility, design and construction supervision of buildings, bridges and civil engineering structures. He has considerable experience in design and construction of reinforced concrete, pre-stressed concrete, steel and composite structures which includes working to British and American standards and the Eurocodes. Saeed has also been contributing to training, development and research in the field of civil and structural engineering and is currently a visiting lecturer at City, University of London. His areas of interest include safety, buildability and durability of structures, post-tensioning, stability of structures and managing risk in civil and structural engineering. Saeed has served on various committees with particular interest in developing and maintaining technical excellence. He is currently chair of the technical committee of the Concrete Bridge Development Group (CBDG) and the B/524 committee responsible for standards for precast concrete products.

Introduction

Feng Fu, City, University of London, UK

David Richardson, University of Leeds, UK

The *Structural Design of Buildings* series provides a comprehensive reference on structural design for practising engineers, university students of civil and structural engineering, as well as other stakeholders such as developer, architect, surveyor and other non-experts in structural design who require reference information and covers the key knowledge required in structural design. The book has been written and edited by a wide selection of leading specialists in each area.

Structural Design of Buildings: Fundamentals in Design, Management and Sustainability focuses on the introduction of general design issues, such as the structural design process, managing risk, loading, materials, sustainability, computational design and building information modelling (BIM). This volume of the manual consists of the following chapters.

Chapter 1 Tackling structural engineering projects
David Richardson introduces issues relevant to bringing a project to a successful conclusion, such as construction contracts and other factors the author has found helpful in his role in delivering major projects, such as delay mitigation and commercial considerations.

Chapter 2 Managing risk in structural engineering
Saeed Ziaie introduces engineering consequence design and risks in the design process. He also introduces CDM, construction time, cost and buildability.

Chapter 3 Structural design processes
Iain A MacLeod shows how to reduce the incidence of errors in structural design. He introduces the process control strategy and technical assessment processes. He also introduces an analysis model to model the process activities. Salam Al-Bizri shows how to achieve zero accidents, zero delays and zero defects in the construction process, introducing the fully integrated organisational framework.

Chapter 4 Loading
RB Marshall covers loading from the context of practising engineers engaged in the design of structures. The different types of loads (dead, live, wind etc.) are categorised and the modes of application are explained.

Chapter 5 Introduction to materials science for structural designers
Fred Veer reviews the most important structural materials and provides an extension on the eco-impact of these materials. Tables of critical properties are also given.

Chapter 6 Advances in concrete technology
Ravindra Kumar Dhir and Chao Qun Lye address the advances made in the field of concrete technology over the years, since the *ICE Manual of Structural Design: Buildings* was published by the Institution of Civil Engineers in 2012.

Chapter 7 Sustainability
Meike Borchers and Elisabeth Marlow consider the application of policies and tools on the low carbon design of buildings, starting with an overview of global and local policy, moving on to how sustainability can be measured, and then addressing the basic principles of sustainability for buildings throughout the design and construction processes.

Chapter 8 Computational design and finite element analysis
Peter Debney introduces the latest developments in computational design, such as parametric modelling and the basic finite element methods.

Chapter 9 Automated BIM collaboration
Sepehr Abrishami demonstrates how blockchain combined with a work breakdown structure and a BIM platform may boost collaboration in order to generate efficient and trusted workflow scenarios that can overcome many of the challenges which arise from traditional building techniques.

The above chapters are part of the *Structural Design of Buildings* series providing guidance on the structural design of buildings. When read in conjunction with the two other volumes in the series, the range of topics covered will provide the reader with a sound understanding of the design and management processes required when embarking on the structural design of a building. We do hope this book will provide some useful guidance to its readers.

Feng Fu and David Richardson
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Chapter 1
Tackling structural engineering projects

David Richardson
University of Leeds, UK

1.1. Introduction

Structural engineering projects are large and complex. When we are new to the design/procurement process, the size and complexity of these projects can seem daunting. There is not a 'one approach fits all' solution that can be adopted to tackle these projects, but there are some general guidelines and processes that can help guide us successfully through the trials and tribulations we will undoubtedly face.

After working in the civil/structural design consultancy sector for over 27 years, including leading the civil/structural design on several 'mega' projects, the author aims to pass on some of the experience gained to the audience. Hence, this chapter is not written from an academic perspective; it is written based on the author's own experience and will hopefully be helpful to practising engineers as they tackle structural engineering projects of their own.

Since this book is focused on design, this chapter is focused on the management and delivery of issues related to the design of civil/structural engineering building projects, not on the management and delivery of the construction.

The author is aware there will be a wide range of readers consulting this material. Some readers will be vastly experienced in the delivery of designs related to structural projects, while others may be taking their first steps. Then, the type of projects under consideration will vary wildly. Some projects may be mega, with contract values in the tens of millions, or even hundreds of millions of pounds. Others, such as domestic dwellings, may be small with contract values of only a few thousand pounds. This means there is not a 'one approach fits all' solution. The author has experience leading the structural design on projects ranging from a few thousand pounds in contract value up to mega projects with contract values more than £0.5 billion. In the author's experience, whether a project is small, medium or large, the challenges faced during the design process are not dissimilar. There needs to be some adaptability applied by the managing engineer depending on the size of the project, but the design management principles applied to small projects can usually be adapted for use on large projects and vice versa.

1.2. Design development

Whether a project is large or small, the final solution is very rarely identical to the design that was envisaged at project conception stage. Design is an iterative process that continues throughout the design development stage of a project. One common analogy used for illustrating the design development process in the manufacturing industry is that of a seven-spoked wheel, with each spoke representing a different stage in the design process and consisting of a specific stage or process, the seven design stages being as follows

1. define the problem
2. conduct research
3. brainstorm and conceptualise
4. create a prototype
5. select and finalise
6. product analysis
7. improve.

This is illustrated diagrammatically in Figure 1.1.

Although this wheel analogy is helpful for illustrating the design process for a manufactured product, it cannot be directly applied to a structural engineering project. In the manufacturing industry, products are usually developed through stages 1–4 and then a prototype is made. This prototype is then tested, and stages 1–4 are repeated in an iterative manner before the final product is approved for mass manufacture. In the manufacturing industry this is essential since a company may be manufacturing thousands or even millions of units and any faults in these could result in costing the manufacturer hundreds of thousands of pounds in rectification costs, notwithstanding the loss to their reputation.

In the construction industry, most projects are bespoke and do not fit this design process model precisely. Construction projects will go through the 'define the problem', 'conduct research' and

Figure 1.1 Manufacturing design process (Note: all author's own)

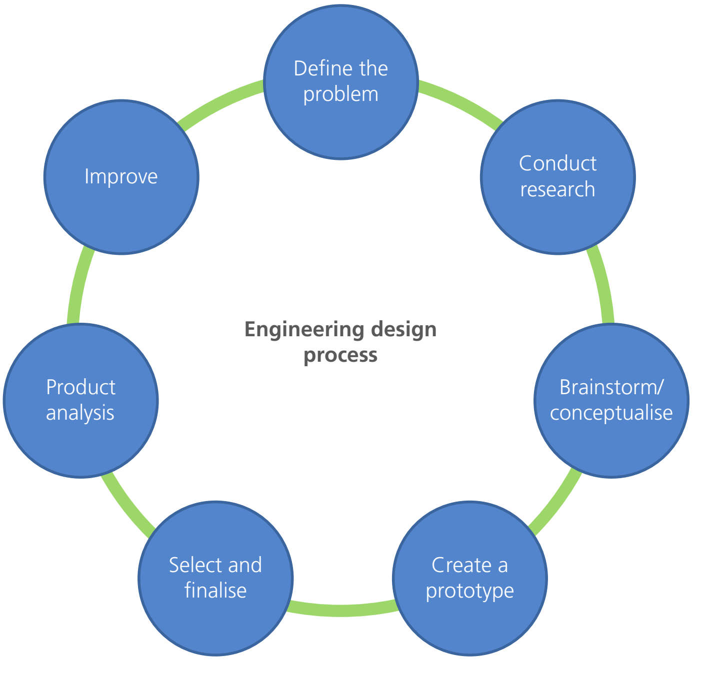
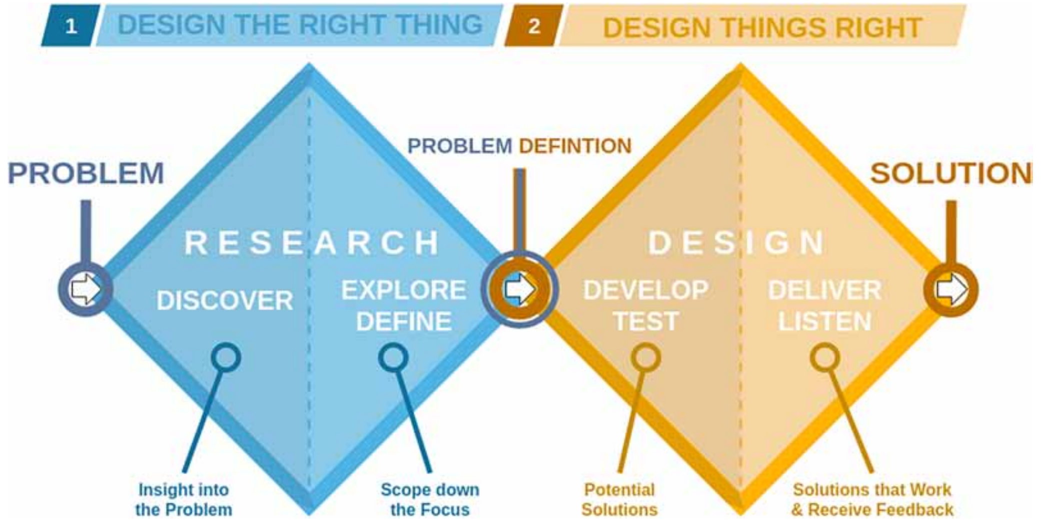


Figure 1.2 Double diamond design process (This file is licensed under the Creative Commons Attribution-Share Alike 4.0 International license)



'brainstorm and conceptualise' stages, but generally there are no 'create prototype', 'select and finalise', 'product analysis' or 'improve' stages. The design process followed in most construction projects can be illustrated using the 'double diamond' model shown in Figure 1.2.

The double diamond design process is a framework used to guide and structure the design thinking process. It was developed by the British Design Council and is widely used in various design fields, including product design, service design and user experience design. The process consists of four distinct phases: discover, define, develop and deliver.

Discover: in this phase, the design team seeks to gain a deep understanding of the problem or challenge at hand and the needs of the users. The team conducts research, gathers information and generates insights. The goal is to identify opportunities and potential areas for innovation.

Define: once the design team has gathered insights from the discovery phase, it moves on to defining the problem statement. This involves synthesising the research findings and identifying the core issues and challenges to be addressed. The team seeks to reframe the problem in a way that allows for creative solutions and ideation.

Develop: in the develop phase, the design team focuses on generating ideas and exploring potential solutions. This involves brainstorming, prototyping and testing different concepts. The emphasis is on divergent thinking, encouraging a wide range of ideas and possibilities. The team explores multiple options and selects the most promising ones to move forward.

Deliver: the final phase of the double diamond process is the deliver phase. Here, the design team narrows down the ideas and solutions from the previous phase and develops them further. The team refines and iterates on the selected concepts, creating detailed designs and prototypes. The goal is to create a tangible solution that can be implemented or delivered to the users or stakeholders.

It is important to note that the double diamond process is not necessarily a linear process. It often involves iterating and cycling back between the different phases as new insights and information are discovered. This iterative approach allows for continuous learning and improvement throughout the design process.

1.3. Project procurement

While both the engineering design process and double diamond design models are theoretical, they can be applied directly in the development of project design. However, in reality, many professional bodies in countries around the world have developed 'plans of work' to assist with the procurement of a project that formalise the process for all relevant stakeholders.

In many countries there is no formal set process for designing a building. 'The way to do it' is unwritten and unrecorded, with informal processes handed down from one generation of professionals to the next. Regardless of where in the world a building is required, the core tasks are broadly the same

- agree appointments with the professional team
- develop a brief with the client
- create concept design options
- coordinate the design
- prepare a planning application
- apply for planning consent
- develop a set of construction information
- prepare a tender
- obtain consents required prior to construction
- award a building contract
- construct the building
- inspect the construction as it progresses
- hand over the building.

When buildings are designed using repeatable, consistent and intuitive processes, this informal approach works – for example, when a clear process for briefing and design is aligned to a consistent means of obtaining statutory consents and where a single procurement route is consistently used. As the design process becomes more complex, influenced by many factors – such as new forms of procurement, modern methods of construction or new drivers, for example sustainability and maintainability – this approach becomes unsustainable. Without a process map, different members of the project team will have different versions of the 'right way to do it', making it inevitable that the project will be undertaken inefficiently.

There are several design process maps, or plans of work, used throughout the world to guide clients through briefing, design and construction, handover and beyond. In most countries, the process maps are set by the professional institutes or by sector bodies. Table 1.1 illustrates some of these. Some have pre-design stages, some do not. Some go beyond completion of construction, others do not. All have construction as a single stage.

There are several key differences between these international plans of work.

- Some incorporate tendering stages, while others are procurement agnostic, focusing on the design rather than procurement process.

- The number of design stages varies from two to four. This underlines the challenges in the design process and the need to divide design into a number of coherent stages, each with a clearly defined purpose, prior to construction commencing.
- Few consider the importance, and benefit, of good briefing, including identifying the need for a building at the outset and how to use feedback from previous projects to inform the brief.
- Not all consider the life of the building beyond construction. However, some are beginning to address this, as well as how the design process and the handover processes impact on a building's performance.

Although each of these plans of work is different, they all have the same goals: to provide the project team with a road map for promoting consistency from one stage to the next, and to provide vital guidance to clients undertaking perhaps their first and only building project.

A comparison of international plans of work is shown in Table 1.1.

In the UK the two most common 'plans of work' are contained in the ACE (Association for Consultancy and Engineering) Conditions of Engagement and the RIBA (Royal Institute of British Architects) Plan of Work. The work plan set out in the ACE Conditions of Engagement is used for works of both a civil engineering and structural engineering nature but, where the 'structural' project is of a 'building' nature, it may be more appropriate to adopt the RIBA Plan of Work as this is more closely aligned to how the design and construction of a building project, as opposed to a civil engineering project, is procured.

1.4. RIBA Plan of Work (RIBA, 2020)

The RIBA Plan of Work is a framework used in the UK construction industry to guide the progression of a project from its inception to completion. It breaks down a project into various stages, from initial conception to completion as follows.

- **Stage 0: Strategic definition.** This is the initial stage where the client's objectives, project feasibility and strategy are defined. It includes tasks like preparing a project brief and assembling the project team.
- **Stage 1: Preparation and briefing.** In this stage, the project brief is developed further. The design team is appointed and initial feasibility studies are conducted. The project objectives and requirements are refined.
- **Stage 2: Concept design.** This stage involves the development of initial design concepts. It is where the broad design ideas take shape, and sketches and drawings are used to convey the concept.
- **Stage 3: Spatial coordination.** Here, the concept design is developed further into a detailed design. It includes architectural, structural and building services designs.
- **Stage 4: Technical design.** This stage involves preparing detailed technical drawings and specifications. It is where the project becomes highly detailed and ready for construction.
- **Stage 5: Manufacturing and construction.** During this stage, the project goes through the construction phase and the building is physically constructed.
- **Stage 6: Handover.** This stage deals with the handover of the completed building to the client. It includes tasks like commissioning, testing and obtaining necessary certificates.
- **Stage 7: Use.** This stage deals with the post-occupancy phase, where the building is in use. It includes monitoring and evaluation of how well the building performs.

Further detail of what each of these stages entails is outlined below.

Table 1.1 A comparison of international plans of work (data taken from RIBA Plan of Work (RIBA, 2020))

	RIBA Plan of Work		ACE (Europe)		AIA (USA)		APM (Global)		NATSPEC (Aus)	
Pre-design	0	Strategic definition	0	Initiative	–	NOT USED	0	Strategy	–	NOT USED
	1	Preparation and briefing	1	Initiation	–	NOT USED	1	Outcome definition	–	Establishment
Design	2	Concept design	2.1	Concept design	–	Schematic design	2	Feasibility	–	Concept design
	–	NOT USED	2.2	Preliminary design	–	NOT USED	–	NOT USED	–	Schematic design
	3	Spatial coordination	2.3	Developed design	–	Design development	3	Concept design	–	Design development
	4	Technical design	2.4	Detailed design	–	Construction documents	4	Detailed design	–	Contract documentation
Construction	5	Manufacturing and construction	3	Construction	–	Construction	5	Delivery	–	Construction
Handover	6	Handover	–	NOT USED	–	NOT USED	6	Project close	–	NOT USED
In use	7	Use	4	Building use	–	NOT USED	7	Benefits realisation	–	Facility management
End of life	–	NOT USED	5	End of life	–	NOT USED	–	NOT USED	–	NOT USED

1.4.1 Stage 0: Strategic definition

RIBA Stage 0: Strategic definition is the first stage and is primarily focused on establishing the project's strategic objectives and setting the foundation for the entire project. Below are the key aspects of RIBA Stage 0.

a) **Project initiation.** This stage involves identifying the need for a building or construction project. It includes determining the project's purpose, scope and feasibility. Key questions are addressed, such as why the project is needed, what it aims to achieve and how it aligns with the client's overall strategic goals.
b) **Strategic briefing.** During Stage 0, the project's strategic brief is developed. This document outlines the client's aspirations, objectives and requirements for the project. It may also include initial budget and time constraints.
c) **Appointment of consultants.** In some cases, consultants such as architects, engineers and project managers may be appointed or selected during this stage. Their expertise is essential in helping the client define the project's strategic objectives.
d) **Site selection.** If the site for the project has not already been chosen, this stage may involve preliminary site assessments and selection based on the project's requirements and location criteria.
e) **Initial feasibility studies.** Initial assessments of the project's feasibility may be conducted, including a review of regulatory and planning constraints, environmental considerations and any potential risks or challenges.
f) **Development of a project team.** Establishing the core project team, including the client, architects, consultants and other key stakeholders, is crucial during this stage. Effective communication and collaboration are essential for a successful project.
g) **Approval and funding.** Securing the necessary approvals and funding for the project is a critical part of Stage 0. This includes obtaining internal or external funding commitments and any required permissions or permits.
h) **Project objectives.** Defining clear project objectives, including quality, sustainability and performance criteria, is essential to guide decision-making throughout the project's lifecycle.

By the end of RIBA Stage 0, the client should have a clear understanding of the project's strategic direction, objectives and initial constraints. This information serves as the basis for proceeding to the subsequent stages of the project, where detailed design and construction planning take place. The outcome of Stage 0 is typically a formal project brief that will guide the project through the subsequent RIBA stages, leading to the successful delivery of the construction project.

1.4.2 Stage 1: Preparation and briefing

RIBA Stage 1 is the second stage the RIBA framework; below are the key aspects of RIBA Stage 1.

a) **Inception.** The project begins with the identification of a need or opportunity for a new building or renovation. This could be initiated by a client, organisation or developer who has a vision for a building project.
b) **Strategic definition.** During this stage, the client and the project team work together to define the project's objectives and requirements. Key tasks and activities in this stage include
    i) establishing the project's goals, budget and timeline
    ii) identifying stakeholders and their needs
    iii) conducting feasibility studies and site assessments

  iv) establishing the initial project brief, which outlines the project's scope, purpose and key features
  v) evaluating any legal or regulatory constraints that may affect the project.

c) **Preparation and brief**. This is the heart of RIBA Stage 1 and involves the development of a comprehensive project brief. The project brief is a document that outlines in detail what the client wants to achieve with the project. It typically includes information such as
  i) project objectives and goals
  ii) spatial requirements (e.g. room sizes, layouts)
  iii) functional requirements (e.g. the intended use of the building)
  iv) budget constraints
  v) sustainability goals
  vi) any specific design or aesthetic preferences
  vii) any other relevant information that will guide the design process.

d) **Business case**. In addition to the project brief, the project team may also develop a business case during RIBA Stage 1. This document helps justify the investment in the project by assessing its financial viability and potential return on investment.
e) **Project strategy**. The project strategy may be developed during this stage to outline how the project will be delivered. It can include decisions about project procurement, design and construction approaches, and the roles and responsibilities of key team members.
f) **Design quality management**. Ensuring the quality of the design is a key consideration in RIBA Stage 1. The project team may set out criteria and objectives for design quality and establish processes for design review and evaluation.

By the end of RIBA Stage 1, the client and project team should have a clear understanding of the project's goals, requirements and constraints. This information serves as the foundation for moving into the subsequent stages of the RIBA Plan of Work, where detailed design, construction and project delivery take place. RIBA Stage 1 essentially sets the project on the right path by defining its purpose and parameters before diving into the more detailed design and construction phases.

1.4.3 Stage 2: Concept design

RIBA Stage 2: Concept design is the third stage in the traditional design and construction process used in the UK and some other countries and is a critical step in the development of a building project. This stage focuses on developing the initial design concept based on the project brief. Below are the key aspects of RIBA Stage 2.

a) **Developing the design concept.** Architects and designers work to create a design concept that responds to the client's brief and aspirations. This includes considering the building's form, layout and overall appearance.
b) **Feasibility studies.** During this phase, designers may conduct feasibility studies to assess the viability of the design concept. This could involve site analysis, structural assessments and environmental impact assessments.
c) **Preliminary design development.** The concept is further developed into a more detailed design. This includes refining the building's layout, size and shape, as well as exploring materials and building systems. Early design sketches and drawings are created to help communicate the design intent.