Dissecting Geometry

Creative Learning
Teacher Resource

Dissecting Geometry
Notes for teachers

Dissecting Geometry is part of a series of workshops that use the site and building of the Sydney Opera House as a catalyst for learning about science, technology, engineering, arts, architecture and maths - transforming the way we understand STEM subjects and ideas through the creative and performing arts.

The workshops can be delivered alongside a tour of the House exploring First Nations perspectives, the architectural practice of Jorn Utzon and his collaborators, as well as the contemporary uses of the site as a world-class performing arts venue

– The following teacher resource contains video links and suggested activities to build on an excursion to Dissecting Geometry in the Centre for Creativity.

Teaching points:
Ideas for teaching and learning in the classroom

We recommend using this resource as a starting point, to adapt content in a way that suits the learning needs of your students. Outcomes include:

- **Subject areas:** Mathematics, Visual Arts, Design and Technology, History and STEM.
- **Cross curriculum priorities:** Sustainability, Aboriginal and Torres Strait Islander Histories and Cultures.
- **General capabilities:** Numeracy, Critical and Creative Thinking, Personal and Social Capability.

In this resource you can find:

- A brief history of the Opera House and the Spherical Solution
- Glossary of built environment roles and careers
- World heritage listing and the *Utzon Design Principles*
- First Nations perspectives for design and architecture

Dissecting Geometry
Workshop Overview

Students develop a series of drawings through observing the structure of the building, and work with archival photographs and objects to dissect the mathematical patterns, additive and pre-fabricated elements of the building to create new or alternative versions of the Opera House. From here, students will use installation and sculptural processes to enlarge, distort, emphasise and recreate aspects of the building from different perspectives.

Dissecting Geometry

In this workshop, students will:

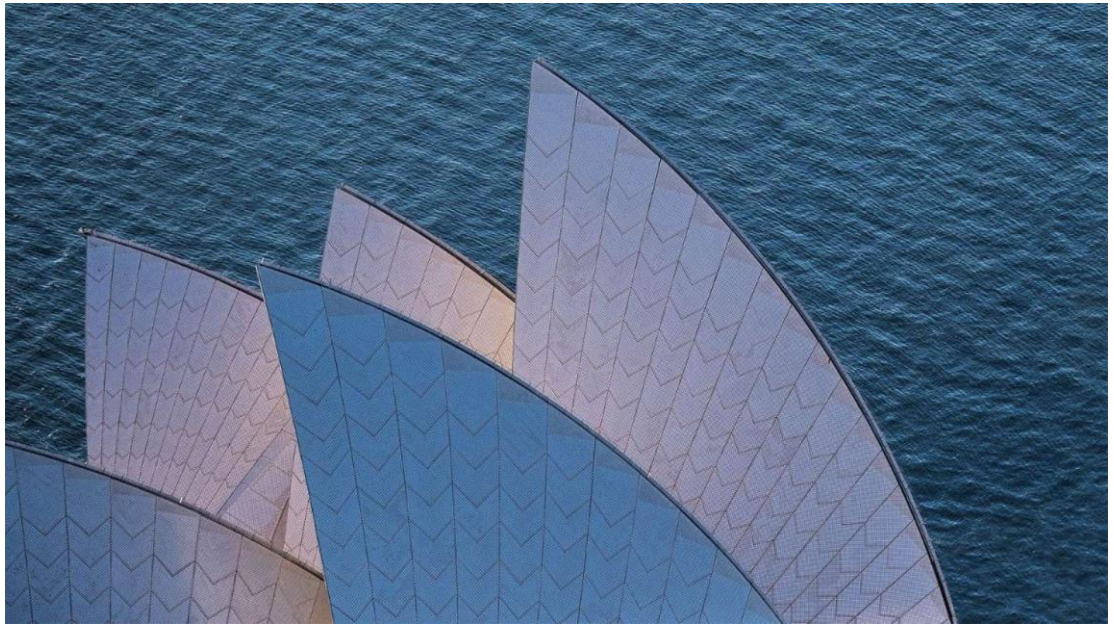
- create a series of observational sketches, collaborative three-dimensional drawings and small sculptural models that replicate the geometry of the Sydney Opera House
- work with peers to distort and abstract patterns and structures of the Opera House to create new imagined versions of the Opera House and surrounding buildings
- develop an understanding of the Utzon Design Principles, in particular Utzon's use of additive architecture, counterbalance, sculpture and form
- interrogate historic and contemporary maps, photographs, drawings and models of the Sydney Opera House and consider how architects, engineers and builders collaborated and problem solved to create the building seen today

The Opera House and the Spherical Solution

The Sydney Opera House was designed for performing arts and cultural experiences

The Opera House is a World Heritage-listed masterpiece of ‘human creative genius’ that belongs to all Australians.

It is the Country’s number one tourist destination and its busiest performing arts centre, welcoming more than 10.9 million visitors a year on site and hosting more than 1,800 performances attended by more than 1.4 million people.

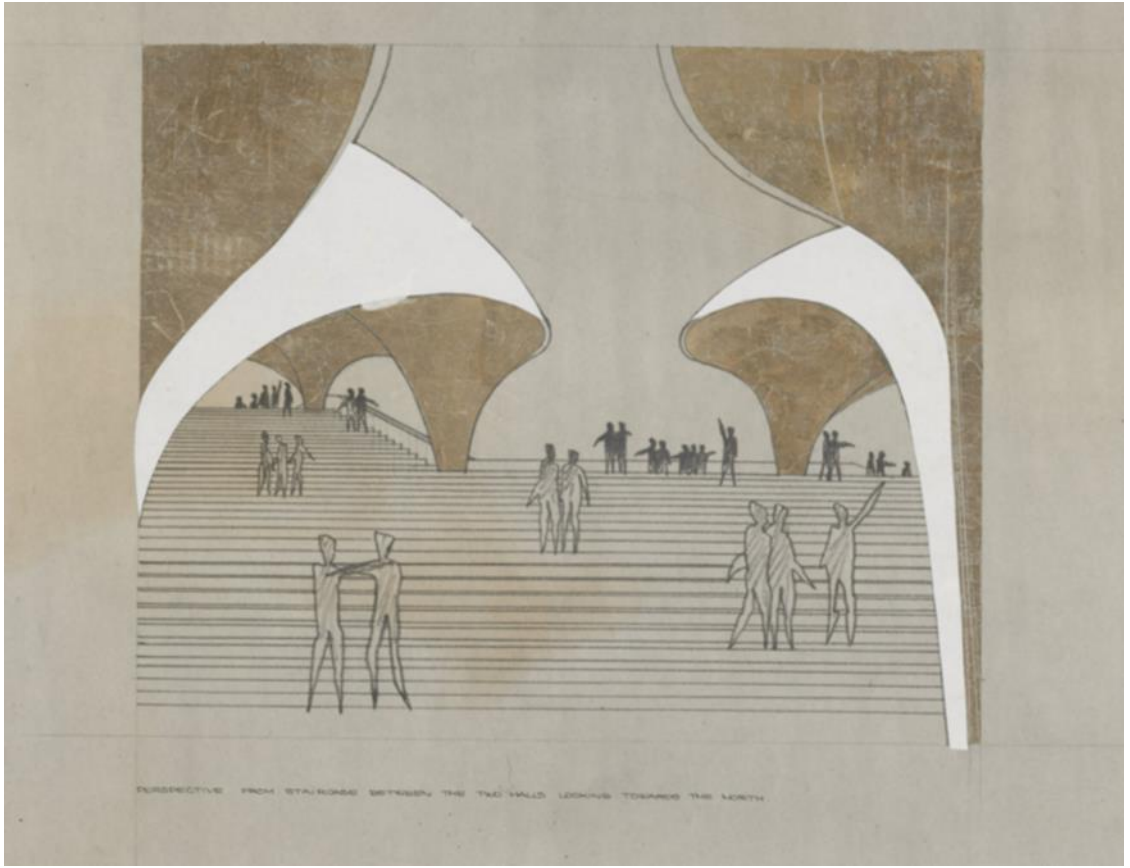


Jørn Utzon is a Danish architect who designed the Opera House

His design was received in 1957, there were 223 entries from 28 countries.

Utzon was announced the winner, receiving £5000 for his design. His drawing presented an idea in a unique and unconventional way, and used gold leaf, pencil and white paper.

The Opera House was completed and opened in October 1973.



The Spherical Solution is the name of the mathematical and engineering principle used to help build the roof of the Opera House

To work out how to build the shells, the engineers at Arup & Partners needed to express the shell shapes mathematically. Asked by the engineers in 1958 to define the curves of the roof, Utzon took a plastic ruler, bent it against a table and simply traced the curves.

A sphere has a single, constant form which can be simply and easily repeated, which are the ‘sail’ or ‘shell’ shapes of the final roof design.

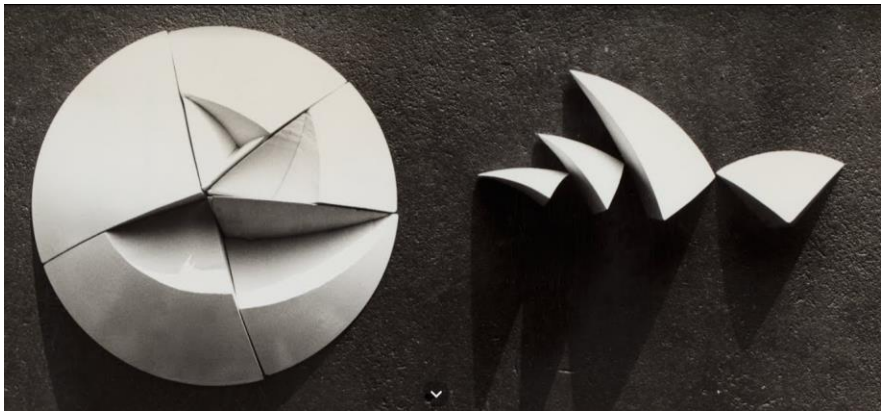
This drawing by Jorn Utzon shows the thinking behind the development of how this design solution was created.

The Spherical Solution as a three-dimensional model

This is where the popular myths comes from – that Utzon was inspired to use a sphere when he had a eureka moment while peeling an orange – it perfectly described the thin shell structure of the roof.

By finding the parts of a sphere that best suited the existing shapes of the shells, each new form could be extracted.

Teaching point: Learn more about the types of physical and digital models created for the Sydney Opera House here.



Teaching points:
A glossary of built environment roles and careers

- **Architect:** someone who designs buildings and communicates their ideas with sketches, technical drawings (hand-drawn or using computer aided software) as well as models and prototypes.
- **Engineer:** someone who uses design processes to solve technical problems, improve systems of working and increase how efficiently something can be produced – like a machine or structure.
- **Builder:** a person who has technical knowledge of a range of materials and uses these to construct buildings or other structures
- **Project Manager:** a person who makes sure big projects (like building the Opera House) can stay within budget, makes sure certain standards are achieved and that projects meet their deadlines.

A comprehensive sustainable buildings glossary can be found here

The tiles of the Sydney Opera House

Utzon wanted the shells to contrast with the deep blue of Sydney Harbour and the clear blue of the Australian sky. The tiles needed to be gloss but not be so mirror-like to cause glare. Utzon was inspired by Japanese ceramic bowls which were slightly coarse and had a granular texture in the clay.

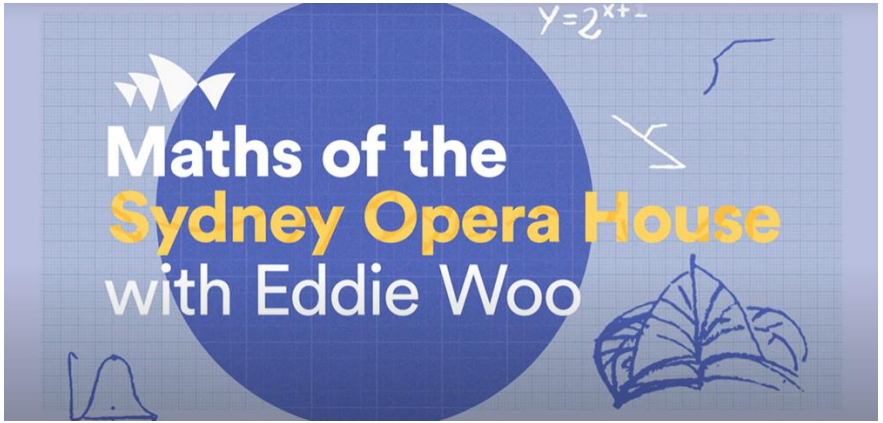
Three years of work by Höganäs of Sweden produced the effect Utzon wanted – 120mm square, made from clay and crushed stone.

Tiles were placed face down in one of 26 chevron shaped beds each with a base shaped to match the curve of the roof. In total, there are 1,056,006 tiles on the roof.

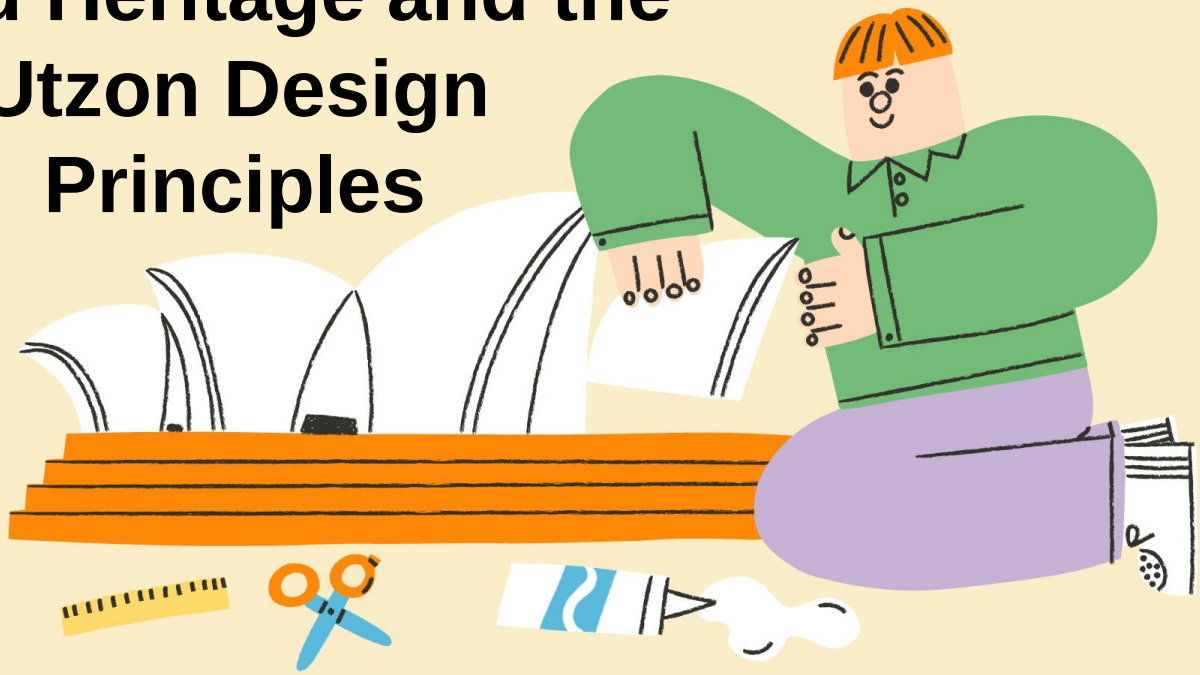
The Purity of Geometry

There are many mathematical concepts behind the construction and design solutions of building the Sydney Opera House, such as algebra, geometry and infinite numbers.

Teaching point: Watch this video with Maths teacher Eddie Woo to find out how geometry and Utzon's 'Spherical Solution' resolved the construction dilemma that the unique design of the arched sails caused with Eddie Woo and Peter Mould, former NSW Government Architect.



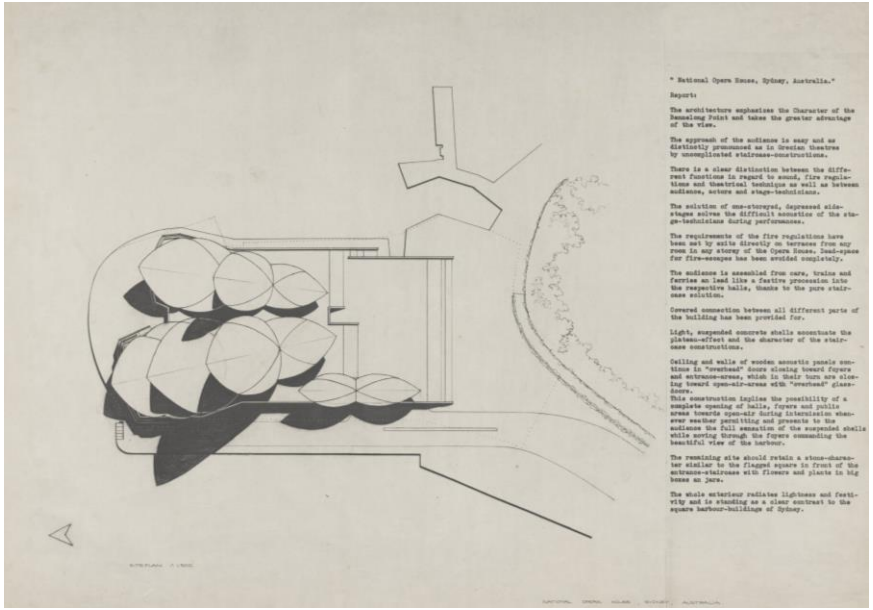
World Heritage and the Utzon Design Principles



The Utzon Design Principles
Overview

*It had a fantastic site, with a beautiful and demanding position on Bennelong Point…I was convinced that a new building in such a position as to be seen from all sides, had to be a large sculptural building. (*Jorn Utzon)

The *Utzon Design Principles* form a document prepared by architects Jørn Utzon and Richard Johnson outlining Utzon's vision for the Sydney Opera House, its setting and his comments on its future. It is the first critical step in the process of establishing a reference point for the conservation of the building.


" National Opera House, Sydney, Australia."

Report:

The architecture emphasizes the Character of the Bennelong Point and takes the greater advantage of the view.

The approach of the audience is easy and as distinctly pronounced as in Grecian theatres by uncomplicated staircase-constructions.

There is a clear distinction between the different functions in regard to sound, fire regulations and theatrical technique as well as between audience, actors and stage-technicians.

The solution of one-storeyed, depressed side-stages solves the difficult acoustics of the stage-technicians during performances.

The requirements of the fire regulations have been met by exits directly on terraces from any room in any storey of the Opera House. Dead-space for fire-escapes has been avoided completely.

The audience is assembled from cars, trains and ferries an lead like a festive procession into the respective halls, thanks to the pure staircase solution.

Covered connection between all different parts of the building has been provided for.

Light, suspended concrete shells accentuate the platean-effect and the character of the staircase constructions.

Ceiling and walls of wooden acoustic panels continue in "overhead" doors closing toward foyers and entrance-areas, which in their turn are closing toward open-air-areas with "overhead" glass-doors.
This construction implies the possibility of a complete opening of halls, foyers and public areas towards open-air during intermission whenever weather permitting and presents to the audience the full sensation of the suspended shells while moving through the foyers commanding the beautiful view of the harbour.

The remaining site should retain a stone-character similar to the flagged square in front of the entrance-staircase with flowers and plants in big boxes as jars.

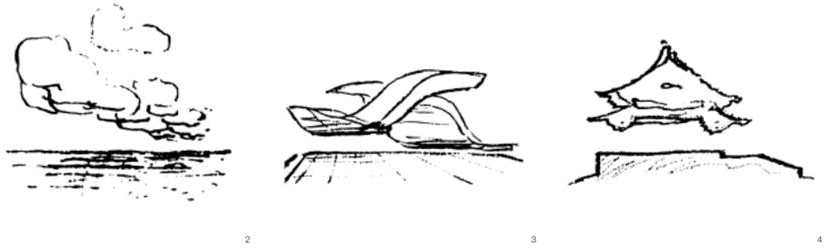
The whole exterieur radiates lightness and festivity and is standing as a clear contrast to the square harbour-buildings of Sydney.

Vision, design and conservation

Sydney Opera House Utzon design principles

Utzon was inspired by organic shapes, nature's colours especially at sunrise and sunset, naval charts and headlands, reflection of sunlight, clouds and birds wings.

Utzon was also interested in how inspiration from nature connected with an experience of the building for the people who visit. Things like bringing joy, feeling like you're in another world, being in a festive mood, feeling detached from the city and how to also create moments of rest.



Teaching points:

- In small groups, research one of the Utzon Design Principles (link above) and present your findings to the class.
- Identify in images and on maps of the Opera House where you might find these Design Principles expressed on the building itself
- Analyse a building in your local area. In what ways does that building relate to Utzon's key design ideas?

The Utzon Design Principles
Prototypes and prefabrication

Building the Opera House was incredibly difficult. Using expertise from design, engineering and computer science, Utzon's plans were able to come to life. Following a long process of trial and error, Utzon and his team problem-solved the design with many sketches, models and prototypes.

The Opera House even commenced building when the working drawings had not yet been completed or finalised. Once builders and engineers were happy with the prototype, a mould or blueprint of the final sections could be made replicated. From this, all the required pieces could be produced and pre-made (or prefabricated) quickly and easily.

World Heritage
Valuing an icon

Sydney Opera House stands by itself as one of the indisputable masterpieces of human creativity, not only in the 20th century but in the history of humankind (International Council Report on Monuments and Sites to the World Heritage Committee).

On 28 June 2007 the Sydney Opera House was included on the UNESCO World Heritage List under the World Heritage Convention, placing it alongside the Taj Mahal, the ancient Pyramids of Egypt and the Great Wall of China as one of the most outstanding places on Earth.

According to UNESCO, the Sydney Opera House is a great architectural work of the 20th century that brings together multiple strands of creativity and innovation in both architectural form and structural design. “Its significance is based on its unparalleled design and construction,” UNESCO stated. “It is a daring and visionary experiment that has had an enduring influence on the emergent architecture of the late 20th century

The design represents an extraordinary interpretation and response to the setting in Sydney Harbour. The Sydney Opera House is also of outstanding universal value for its achievements in structural engineering and building technology. The building is a great artistic monument and an icon, accessible to society at large.”

Curriculum connections and further research

Curriculum Links

The following subjects and themes can be explored in the classroom

The excursion supports the **Mathematics** by emphasizing geometric concepts such as symmetry, proportions, and spatial reasoning, applying these principles to the study of architectural structures.

The program connects with **Science** by exploring the materials, physics, and environmental impact of the Sydney Opera House, applying scientific principles to understand the building's structural integrity and sustainability.

Students will engage with **Visual Arts** by creating detailed drawings and sculptural models of the Sydney Opera House, aligning with the NSW Visual Arts Syllabus. This will involve exploring artistic techniques to represent geometric forms and architectural details, enhancing their ability to visualize and interpret design concepts.

In **History**, students will be examining the historical context of the Sydney Opera House's construction, investigating how historical and contemporary architectural practices and technologies contributed to its creation.

Curriculum Links
Cross-curriculum priorities

Aboriginal and Torres Strait Islander Histories and Cultures (Version 8.4)

Country, Culture and People

- OI.2 Aboriginal and Torres Strait Islander communities maintain a special connection to and responsibility for Country/Place.
- OI.9 The significant contributions of Aboriginal Peoples and Torres Strait Islander Peoples in the present and past are acknowledged locally, nationally and globally.

Sustainability (Version 8.4)

Systems, World Views and Futures

- OI.9 Sustainable futures result from actions designed to preserve and/or restore the quality and uniqueness of environments.

iSTEM Process

Students will:

- Identify and define the need
- Apply knowledge and understanding to recognise constraints
- Collaborate to plan model
- Create model to clearly represent the annotated plan
- Test and evaluate the model against the class design; does it fit? Have I met the constraints? Is the model sustainable?
- Share and Communicate

Curriculum Links
General capabilities

LITERACY: Use language to interact with others

- Level 4, Year 6, students: use pair, group and class discussions and informal debates as learning tools to explore ideas and relationships, test possibilities, compare solutions and to prepare for creating texts

- Level 5, Year 8, students: use pair, group and class discussions and formal and informal debates as learning tools to explore ideas, compare solutions, evaluate information and ideas, refine opinions and arguments in preparation for creating texts

- Level 6, Year 10, students: use pair, group and class discussions and formal and informal debates as learning tools to explore ideas, compare solutions, evaluate information and ideas, refine opinions and arguments in preparation for creating texts

NUMERACY: Using spatial reasoning element
Visualise 2D shapes and 3D objects

- Level 4, Year 6, students: visualise, sort, describe and compare the features of objects such as prisms and pyramids in the environment
- Level 5, Year 8, students: visualise, describe and apply their understanding of the features and properties of 2D shapes and 3D objects
- Level 6, Year 10, students: visualise, describe and analyse the way shapes and objects are combined and positioned in the environment for different purposes

Interpret maps and diagrams

- Level 4, Year 6, students: identify and describe routes and locations, using grid reference systems and directional language such as north or north east
- Level 5, Year 8, students: create and interpret 2D and 3D maps, models and diagrams
- Level 6, Year 10, students: create and interpret maps, models and diagrams using a range of mapping tools

Curriculum Links
Australian Curriculum

NUMERACY: Using spatial reasoning elements
Using measurement elements

- Level 4, Year 6, students: choose and use appropriate metric units for length, area, volume, capacity and mass to solve everyday problems
- Level 5, Year 8, students: convert between common metric units for volume and capacity and use perimeter, area and volume formulas to solve authentic problems
- Level 6, Year 10, students: solve complex problems involving surface area and volume of prisms and cylinders and composite solids

CRITICAL AND CREATIVE THINKING: All sub-elements

Level 4, Year 6, students:
- Pose questions
- Imagine possibilities and connect ideas
- Think about thinking (metacognition)
- Apply logic and reasoning

Level 5, Year 8, students:
- Identify and clarify information and ideas
- Consider alternatives
- Reflect on processes
- Draw conclusions and design a course of action

Level 6, Year 10, students:
- Organise and process information
- Seek solutions and put ideas into action
- Transfer knowledge into new contexts
- Evaluate procedures and outcomes

Curriculum Links
NSW Curriculum

English: Stage 5
- EN5-URB-01: evaluates how texts represent ideas and experiences, and how they can affirm or challenge values and attitudes
- EN5-ECA-01: crafts personal, creative and critical texts for a range of audiences by experimenting with and controlling language forms and features to shape meaning (speaking)

English: Stage 4
- EN4-ECA-01: creates personal, creative and critical texts for a range of audiences by using linguistic and stylistic conventions of language to express ideas

English: Stage 3
- EN3-OLC-01: communicates to wide audiences with social and cultural awareness, by interacting and presenting, and by analysing and evaluating for understanding
- EN3-VOCAB-01: extends Tier 2 and Tier 3 vocabulary through interacting, wide reading and writing, morphological analysis and generating precise definitions for specific contexts

All stages working mathematically
- MAO-WM-01: develops understanding and fluency in mathematics through exploring and connecting mathematical concepts, choosing and applying mathematical techniques to solve problems, and communicating their thinking and reasoning coherently and clearly

Mathematics: Stage 5
- MA5-GEO-C-01: identifies and applies the properties of similar figures and scale drawings to solve problems
- MA5-TRG-C-02: applies trigonometry to solve problems, including bearings and angles of elevation and depression
- problems
- MA5-VOL-C-01: solves problems involving the volume of composite solids consisting of right prisms and cylinders
- MA5-LIN-C-01: determines the midpoint, gradient and length of an interval, and graphs linear relationships, with and without digital tools

Curriculum Links
NSW Curriculum

Mathematics: Stage 4
- MA4-GEO-C-01: identifies and applies the properties of triangles and quadrilaterals to solve problems
- MA4-LEN-C-01: applies knowledge of the perimeter of plane shapes and the circumference of circles to solve problems
- MA4-ARE-C-01: applies knowledge of area and composite area involving triangles, quadrilaterals and circles to solve problems
- MA4-DAT-C-01: classifies and displays data using a variety of graphical representations

Mathematics: Stage 3
- MA3-3DS-01: visualises, sketches and constructs three-dimensional objects, including prisms and pyramids, making connections to two-dimensional representations
- MA3-GM-02: selects and uses the appropriate unit and device to measure lengths and distances including perimeters
- MA3-GM-03: measures and constructs angles, and identifies the relationships between angles on a straight line and angles at a point
- MA3-DATA-01: constructs graphs using many-to-one scales

Visual Arts: Stage 5
- 5.4 investigates the world as a source of ideas, concepts and subject matter in the visual arts
- 5.8 uses their understanding of the function of and relationships between artist – artwork – world – audience in critical and historical interpretations of art

Visual Arts: Stage 4
- 4.2 explores the function of and relationships between artist – artwork – world – audience
- 4.6 selects different materials and techniques to make artworks
- 4.9 begins to acknowledge that art can be interpreted from different points of view

Visual Arts: Stage 3
- VAES3.1 Investigates subject matter in an attempt to represent likenesses of things in the world
- VAES3.4 Communicates about the ways in which subject matter is represented in artworks

Curriculum Links
NSW Curriculum

Design and Technology: Stage 5

- DT5-2 applies and justifies an appropriate process of design when developing design ideas and solutions
- DT5-4 analyses the work and responsibilities of designers and the factors affecting their work
- DT5-7 uses appropriate techniques when communicating design ideas and solutions to a range of audiences

Design and Technology: Stage 4

- DT4-2 describes and follows a process of design when developing design ideas and solutions
- DT4-4 describes the work and responsibilities of designers and the factors affecting their work
- DT4-7 communicates design ideas and solutions using a range of techniques

Resources
More about the Sydney Opera House

Sydney Opera House: Our Story
- https://www.sydneyoperahouse.com/our-story

How we work – strategic plans and programs
- https://www.sydneyoperahouse.com/about-us/how-we-work

Community projects
- https://www.sydneyoperahouse.com/about-us/in-the-community

Careers and opportunities
- https://www.sydneyoperahouse.com/about-us/careers-and-other-opportunities

Creative Learning resources
- https://www.sydneyoperahouse.com/learn/teachers-and-students/classroom-resources

50th Anniversary Celebrations
- https://www.sydneyoperahouse.com/50

Get in touch

Got questions? Contact us with any enquiries about our education programs for schools via phone or email.

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