Lightweight framing

Lightweight framed construction is the most common construction system in Australia. The two most commonly used framing materials — steel and timber — can contribute to the comfort, appeal and environmental performance of your home. Although lightweight framed construction can be used for floors, walls and roofs, the focus of this article is on wall systems.

Timber from sustainable sources provides a renewable building material that takes in carbon from the atmosphere while growing and stores it for the life of the building. Its greatest enemy is the termite, although rot and mould from condensation is becoming an increasingly critical threat as we seal our homes and increase insulation levels.

Steel-framed construction began to be adopted in the 1940s and continues to gain popularity. Its many advantages include being durable, stable and termite-proof. Steel production requires large amounts of energy but steel is 100% recyclable and current framing products often include recycled content (up to 40%).

Lightweight framed construction can provide effective housing solutions in all climate zones.

The lightweight house is particularly suited to creating cost effective, flexible design solutions to the challenges of steep sites and reactive soils (see Challenging sites). Appropriate design strategies that include alternative sources of thermal mass can also deliver best practice, passive design outcomes — often with lower embodied energy than traditional high mass systems (see Thermal mass). This can result in lower life cycle energy use. (see Embodied energy; Design for climate; Passive solar heating; Passive cooling)

Lightweight floor frames can support internal and external wall, floor and roof loads on low impact footing systems. Lightweight houses are well suited to above-ground construction to minimise site disruption. Framed structures lend themselves to the creation of houses with diverse openings for passive solar heating, natural light and ventilation, through the careful design of windows, doors and ventilation paths.

Performance summary

Appearance

Lightweight framed homes can range in appearance from the ultra-modern to the traditional weatherboard bungalow. With the enormous variety of non-structural claddings, linings and finishes available (e.g. reconstituted forestry waste, fibre cement sheet or siding, plywood, weatherboard, brick veneer, or metal) lightweight framed construction can be used to create almost any desired architectural form or finish. (see Cladding)

Lightweight framing can support a range of innovative shading, glazing and lighting solutions to achieve attractive, thermally comfortable homes in all climatic zones. Lightweight framed houses (particularly timber due to its low thermal bridging) can be found in very cold climates such as Scandinavia and Canada through to the very hot tropical climates of South-East Asia. Their appearance varies in response to climate and architectural expression.
Structural capability

Lightweight framing materials have good compressive strength but are strongest in tension. Engineered timber and steel structural design solutions exploit these characteristics to maximise structural capacity whilst minimising materials use, as shown in the design of I-beam structural members, roof trusses and open web joists.

Timber wall frames are typically either 90mm or 70mm deep with 35mm or 45mm thick studs depending on load and spacing — usually 450–600mm. Noggins (spacers) are inserted between studs to provide lateral support. Additional noggin rows are often required for taller walls. Top and bottom plates are typically 90x45mm and can be double thickness depending on the load (e.g. first floor, tiled roof, long truss spans) or the spacing of the supporting floor members.

Steel wall frames are also typically 70mm or 90mm deep, and additional strength is achieved by using thicker gauge steel or additional folds or bends in the cross-section. Stud spacings and noggins are similar to timber.
Openings require lintels (beams). Engineered timber solutions use advanced gluing, laminating and jointing techniques to increase the compressive and tensile strength of lower structural grade timbers and overcome natural weaknesses such as knots, warping, splitting and bowing. Materials include plywood, particleboard and fibreboard as well as engineered products such as glue laminated timber, laminated veneer lumber (LVL) and finger-jointed cladding or fascia. It’s advisable to take particular care when using these products internally, to ensure that they do not contain adhesives that compromise indoor air quality.

Engineered steel solutions use a wide range of steel shaping options such as extruding, bending or folding to gain maximum structural advantage from minimal steel thicknesses. Thin steel sections are strengthened with angles and corners (e.g. Z and C purlins, battens and studs, folded I-beams and dog-bone beams). Hot rolled sections (e.g. U-beams, angles, I-beams and channels) place thicker steel in high tensile or compressive load sections (flanges) held in position with thinner webs where forces are lower.

Framing systems can be varied to suit almost any design or construction system providing engineering certification is obtained.

Common variations in Australia include ‘post and beam’ to provide structural support for roof loads that allow the use of non-loadbearing infill systems including straw bale and mud brick.
Thermal mass

Lightweight framed construction has low thermal mass and is therefore unable to store passive heat or ‘coolt’. This can be an advantage in some climates (e.g. hot and humid) or sites with no solar or cool breeze access. (see Design for climate; Thermal mass; Passive cooling; Passive solar heating)

Highly insulated, low mass houses can respond rapidly and efficiently to auxiliary heating and cooling. In climates where thermal mass storage is desirable, it can be introduced with:

- concrete slabs
- masonry feature walls
- sealed, solar/breeze exposed water containers
- phase change materials (PCMs) (see Thermal mass).

Insulation

Insulation is typically placed, not compressed, between the structural elements (e.g. studs, plates, noggins) and the achievable insulation levels are predominantly dependent on depth (stud size). Bulk insulation performance is reduced if it is compressed because it is the trapped air that insulates, not the material.

Bulk insulation should not be compressed — it is the trapped air that insulates, not the material.

While performance and thickness vary between different types of insulation, 70mm frames generally allow R 1.5 added insulation, 90mm frames allow R2, and 140mm frames allow R3. Upgrading from 70mm to 90mm frame depth adds around 25% to the cost of external frames.

Higher grade insulation can achieve R values up to R0.5 higher within the same thickness without compression. Manufacturers display the rated performance of their products on the packaging and in their promotional material.

While uncommon, 140mm and 190mm frames are available and, in the case of timber, add around 33% and 75% respectively to the cost of timber in the wall and slightly more to the manufacturing cost of a 90mm frame. Each step up in external wall thickness can add 2-3% to the cost of a conventional home; increased insulation levels may be more cost effectively achieved by adding an extra layer of insulating foam, which has the added benefit of limiting conducted heat loss via the framing system, known as thermal bridging or convected heat loss via insulation gaps around the frame.

Steel framing companies can advise on the comparative costs of steel frames.

Steel is an excellent conductor and is by far the greatest source of thermal bridging. While timber is a natural insulator and a poorer thermal bridge, it still typically has a lower R value than insulation materials.

External foam insulation layers generally act as a vapour barrier and can cause condensation on the inside. In climates prone to condensation, a breathable membrane should be installed on the outside of the frame to position bulk insulation, and a 10mm air gap provided between frame and foam layer to drain condensation. (see Cladding; Sealing your home)

The low thermal conductivity of timber reduces but does not eliminate thermal bridging, which can reduce the overall R value of a structure. (see Insulation installation)

Sound insulation

Sound travels via floors, walls and ceilings in lightweight framed buildings, by both direct path and reflection, and each of these elements requires effective sound treatment to ensure acceptable outcomes. This means selecting components with the appropriate sound insulation rating as well as framing details that minimise transmission.

Some key noise attenuation strategies are listed below, but more detailed information is provided in the appendix Noise control.
Weighted sound reduction index (Rw) is the metric used by the Building Code of Australia (BCA) for indicating the effectiveness of a structure as a noise insulator. (Rw rating has replaced sound transmission class (STC) but the two rating systems are similar — see the appendix Noise control.) An increase of one Rw unit approximately equals a reduction of one decibel in noise level. An increase of 10 Rw units approximately halves the sound transmitted. (CSR 2011)

Doors and windows must be effectively sealed. Ventilation and services openings in walls and ceilings are critical contributors to sound transmission. For example, switches and power outlets should never be back to back. Rather, they should be in separate air spaces on either side of a stud or noggin.

The mass of plasterboard per unit area is very important in determining the Rw or STC: the heavier the layers, the better. Most manufacturers produce a high density acoustic board in varying thicknesses. Due to handling limitations, multiple layers are often the preferred solution. Joints should be staggered in multiple layer applications.

Typical multiple acoustic board layers to achieve various levels of noise insulation.

Structural separation is one of the most effective noise reduction methods. Walls with staggered studs or double stud construction are most effective. Resilient furring channels (e.g. top hat steel battens) fixed to every second stud via a resilient clip are commonly used to achieve structural separation. Resilience allows the channel or clip to bend, stretch or compress and then regain its shape, absorbing or ‘damping’ rather than transmitting impact noise.

Structural isolation systems or resilient channels made from sound absorbing or high loss materials increase structural separation. Several varieties are available from manufacturers.

Damping using high loss material (rubbery, tarry or plastic based materials) is effective in reducing the transmission of impact sounds. Various sound damping sheet products are commercially available and are particularly appropriate for floors. Some have an adverse impact on air quality.

Source: Forsythe 2004

Three different methods for achieving structural separation within a frame.
Sound absorbing insulation is most effective when the faces are structurally isolated. When the two layers forming the wall cavity do not have rigid connections between them, the addition of sound-absorbing material to the cavity increases the $R_w$ by about 10 points.

Sound absorbing surfaces added to the surface of walls and floors can reduce reflected sound but not direct noise transmission. Carpet consistently outperforms other floor coverings in this regard. It reduces reflection and absorbs impact but has significant waste implications.

Depth of cavity (i.e. the distance between the inner faces of the plasterboard) is a very important factor in the control of sound transmission. Canadian research (Quirt et al. 1995) shows that the greater the distance, the higher the $R_w$ value (when sound absorbing insulation is included).

Framing material — Canadian tests indicate that steel framed wall construction performs better than timber framed construction in standard, unseparated applications (Quirt et al. 2005).

Fire resistance
Timber maintains structural integrity longer than steel, which loses strength rapidly when exposed to heat.

Where timber is used extensively in exterior applications and around the house, AS 3959-2009, Construction of buildings in bushfire-prone areas, specifies categories of fire risk and defines compliance measures for each.

Fire rated plasterboard in varying thicknesses and configurations can be used to achieve Building Code of Australia (BCA) required fire ratings for all Class 1 and 10 building applications. Manufacturers provide detailed instructions and explanations.

Multi-residential timber framed construction
Multi-residential timber framed construction (MRTFC) uses fire and sound-rated timber framed wall and floor systems to provide vertical and horizontal separation between dwellings. It is an innovative use of lightweight framing techniques to deliver cost effective, low mass housing solutions that are highly appropriate for most climates and likely to be better able to respond to climate change. (see Thermal mass)

Its construction provides a carbon sink during building life and, with careful, climate responsive design, MRTFC has very low life cycle carbon emissions. If needed, thermal mass can be added through water filled containers or PCMs. This type of thermal mass allows flexible responses to unpredictable spring and autumn weather in addition to climate change adaptation: just empty the water container or move the PCMs onto the balcony.

MRTFC has been used in Europe and America for many years with excellent results. In Australia, projects range from large multi-level developments to townhouses or villas, including new developments, refurbishments and additions to existing buildings. Methods, techniques and details undergo constant innovation and improvement so pre-project research is essential. (see case studies listed in ‘References and additional reading’)

Vermin resistance
Termites are a major concern in lightweight timber constructions. The two principal methods of dealing with the threat of termites are chemical and physical. Current building regulations (AS 3660-2000, Termite management) emphasise managing termites through physical barrier systems and inspections rather than the environmentally harmful chemical methods of the past.
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Termites attack from underground and the best risk management strategy is to design the house for easy inspection, i.e. leave an accessible space to inspect for termite activity. Physical barriers prevent hidden entry but remember that these are inspection systems rather than prevention systems.

Lightweight timber constructions, especially those with elevated floors or pole framing, lend themselves to easy inspection for termite activity.

Other vermin such as mice can be controlled by ensuring that all cavities are sealed. Bird proofing of roof spaces and wall cavities is essential. Subfloor cavities, eaves, ridges and gable overhangs are common access points. Galvanised chicken wire is a good solution that also keeps rats and mice out.

Durability and moisture resistance

Steel is a very durable material and, if treated to appropriate levels for the corrosiveness of site conditions (see AS 1397-2011, Continuous hot-dip metallic coated steel sheet and strip — coatings of zinc and zinc alloyed with aluminium and magnesium), can deliver long life spans.

Timber is an organic material that deteriorates with weathering and is subject to termite attack as well as mould growth and rot when exposed to water or condensation. While appropriate design detailing and rainproof cladding can protect timber from weathering, it does not protect it from condensation. Water vapour condensing as it passes through walls is arguably becoming the most significant threat to lightweight framed structures. Its prevalence is increasing due to higher insulation and air sealing levels. In addition to increasing the temperature differentials and encouraging water vapour transfer, insulation can become sodden with condensation, reducing its effectiveness and increasing the risk to frame elements.

While steel is not subject to rot and provides limited nutrients for mould growth, condensation absorbed by insulation can damage linings and cause corrosion. Additionally, the conductivity and thermal bridging capacity of steel means that dew point formation within the wall is more likely. (see Sealing your home; Cladding)

Environmental impacts

Timber and steel framing materials compared on a single indicator ‘environmentally preferred’ basis

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Timber frame</th>
<th>Steel frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>From a renewable source</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Sustainably sourced</td>
<td>✓ mostly</td>
<td>×</td>
</tr>
<tr>
<td>Sustainably manufactured</td>
<td>✓ mostly</td>
<td>×</td>
</tr>
<tr>
<td>Non-toxic during use</td>
<td>✓ (if untreated)</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Low in embodied carbon</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>Recycled content</td>
<td>×</td>
<td>✓ ✓ frequently</td>
</tr>
<tr>
<td>Recyclable</td>
<td>× (very limited)</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Low waste rates</td>
<td>✓ (if factory made)</td>
<td>✓ ✓</td>
</tr>
<tr>
<td>Appropriate for life span</td>
<td>✓ (if termite treated)</td>
<td>✓ (galvanise in corrosive environment)</td>
</tr>
<tr>
<td>Thermal bridging</td>
<td>✓</td>
<td>× (unless externally insulated)</td>
</tr>
<tr>
<td>Flexibility and adaptability</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

The simplistic pass/fail analysis of single indicators in the table confirms that both commonly used framing materials have environmental advantages and disadvantages. But is the indicator list exhaustive? The answer is clearly no.

How then do we choose the indicators and rank them in importance to make a fully informed decision? For example, would fire performance be a useful indicator? How much does it matter if timber is not easily recycled when it is a carbon sink? How toxic are the chemicals used to treat timber for termites and how does this compare to carbon, water and other environmental emissions from steel production?

While these important single indicators can inform simple choices in an individual application where life span and site conditions are known, they are incomplete and therefore inappropriate and even misleading for generic comparisons. Life cycle assessment (LCA) considers all the environmental emissions and depletions of a material from cradle to grave (or cradle to cradle if they are reused or recycled) and applies a weighting system to prioritise the most urgent or serious. LCA is beyond the scope of most builders and designers, so we need a simple rating system based on LCA to help us choose between products.
Embodied energy

Embodied energy is an important point of differentiation between steel and timber lightweight framing. The following tables can inform your choice.

Carbon released and stored in the manufacture of building materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Carbon released (kg/t)</th>
<th>Carbon released (kg/m³)</th>
<th>Carbon stored (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawn timber</td>
<td>30</td>
<td>15</td>
<td>250</td>
</tr>
<tr>
<td>Steel</td>
<td>700</td>
<td>5,300</td>
<td>0</td>
</tr>
<tr>
<td>Concrete</td>
<td>50</td>
<td>120</td>
<td>0</td>
</tr>
<tr>
<td>Aluminium</td>
<td>8,700</td>
<td>22,000</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: Ferguson et al. 1996

Energy used in manufacturing

Most energy is consumed during the processes of manufacturing. The table below shows that manufacturing rough sawn timber uses substantially less fossil fuel energy per unit volume than steel, concrete or aluminium; however, significantly lower volumes of steel are used in lightweight steel framing than timber in timber framing.

Additionally, steel is 100% recyclable at the end of its life. Currently around 80% is recycled, a process that requires up to 70% less energy than the original manufacturing. New steel frames currently include 30–40% recycled steel, the percentage varying with supply. (Carre 2011)

Fossil fuel energy used in the manufacture of building materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Fossil fuel energy (MJ/kg)</th>
<th>Fossil fuel energy (MJ/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawn timber</td>
<td>1.5</td>
<td>750</td>
</tr>
<tr>
<td>Steel (virgin)</td>
<td>35</td>
<td>266,000</td>
</tr>
<tr>
<td>Concrete</td>
<td>2</td>
<td>4,800</td>
</tr>
<tr>
<td>Aluminium</td>
<td>435</td>
<td>1,100,000</td>
</tr>
</tbody>
</table>

Source: Ferguson et al. 1996

A more useful metric is embodied energy per unit area of assembly over life span, summarised below.

Embodied energy (EE) per unit area of assembly over life span

<table>
<thead>
<tr>
<th>Material</th>
<th>Initial EE of walls (MJ/m²)</th>
<th>Maintenance EE over 40 years (MJ/m²)</th>
<th>Total EE over 40 year life cycle (MJ/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber frame, timber clad, painted</td>
<td>31,020</td>
<td>24,750</td>
<td>55,770</td>
</tr>
<tr>
<td>Timber frame, brick veneer, unpainted</td>
<td>92,565</td>
<td>nil</td>
<td>92,565</td>
</tr>
<tr>
<td>Double brick, unpainted</td>
<td>141,900</td>
<td>nil</td>
<td>141,900</td>
</tr>
<tr>
<td>Autoclaved aerated concrete, painted</td>
<td>76,560</td>
<td>24,750</td>
<td>101,310</td>
</tr>
<tr>
<td>Steel frame, fibre cement clad, painted</td>
<td>75,900</td>
<td>24,750</td>
<td>100,650</td>
</tr>
</tbody>
</table>

From this table, it can be seen that maintenance of painted claddings ranges between 25% and 50% of life cycle embodied energy over a 40-year life span depending on system and climate. It is therefore a critical consideration. (see Embodied energy)

Toxicity and breathability

Steel products are non-toxic during a building’s life but emit significant ecological toxins during production.

Timber growth and production reduce atmospheric carbon levels by taking in carbon dioxide. However, some chemicals used in plantations can adversely affect terrestrial and aquatic environments, and poor forest management can lead to soil loss and degradation.

Timber requires treatment to limit termite attack and rot. Options (Ecospecifier 2012) include the following:

- Light organic solvent particles (LOSP) treatments offer low toxicity preservatives, fungicides and insecticides. Protection levels range from H1 (lowest protection) to H3 (exposed external applications). Unsuitable for in-ground applications.
- Boron and fluorine products are available as paints and provide largely benign preservative, fungicide and insecticide protection for H1–H4 applications. Products are water-soluble and require retreatment at regular intervals.
- Copper azole is a highly effective alternative preservative, fungicide and insecticide suitable for H1–H4 (in-ground) applications. It contains no high
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Toxicity arsenic or chromium compounds and can be burnt and mulched.

- CCA (copper chrome arsenate) solution is not recommended. It emits highly toxic smoke if burned and cannot be mulched. Any quantities, including shavings and offcuts, must be disposed of as landfill. CCA is effectively prohibited in Japan and some European countries and being phased out in the US. Contact with CCA-treated timber may be toxic to young children (Environmental Working Group 2001).

- Glues and solvents used in engineered timber products often contain formaldehyde — a known carcinogen — and volatile organic compounds (VOC) with known adverse implications for human health. Some products now use low formaldehyde and VOC glues (see the appendix The healthy home).

Typical domestic construction

Buildability, availability and cost

Lightweight framed construction is a common and relatively simple building system. Trade skills and availability are abundant.

Timber frames are traditionally erected by carpenters who are skilled and tooled up to work with timber. Although steel framing requires different skill and tool sets, it is gaining in popularity.

Lightweight framing in both timber and steel offers design freedom at a competitive cost. The growing range of engineered solutions continues to extend design possibilities while reducing resource consumption.

Construction process

Typical lightweight construction consists of framed and braced structures with applied claddings. The process of construction may begin with a concrete slab onto which continuous frames are fixed, or with the placement of piers or pad footings to support piers, bearers and joists — a lightweight flooring system.

Lightweight construction allows simpler and more flexible footing design. Various proprietary systems can reduce footing costs and allow builders to ‘get out of the ground’ much faster than high mass construction systems, which require more extensive earthworks.

Roof construction can use prefabricated trusses or conventional framing. Trusses are easily deconstructed and reused on other projects, particularly sheds and outbuildings.

Timber components may be fabricated on site but modern construction techniques generally favour off-site fabrication of trusses and wall frames. On-site fabrication of more complex designs can minimise costly mistakes and overcome small setout errors or dimensional variations in slabs and flooring.

Typical details

Advice from qualified design professionals can save owners and builders time and money.

All structural design should be undertaken in accordance with the relevant Australian Standard or certified by a practising structural engineer or accredited supplier. Lightweight framed construction is regulated under BCA Volume 2, Class 1 and 10 Buildings: Housing Provisions: Part 3.4.2 Steel framing and Part 3.4.3 Timber framing. ‘Deemed to comply’ bracing and tie-down details are provided in the BCA.

Footings

A substructure of piers, piles, stumps, posts, dwarf brick walls or perimeter masonry walls support the building frame.

The substructure carries the load to the footings which, depending on local practice, may consist of sole plates of durable or treated timber on a concrete pad, or a reinforced concrete strip footing.

The use of piers and posts can greatly reduce the need for cut-and-fill on sloping blocks (see the appendix Sediment control).

Innovative tensile foundation structures can accommodate the most challenging of sites (see Challenging sites).

Frames

A lightweight frame is like a skeleton to which exterior wall claddings, internal linings, flooring, roofing, windows and doors are attached.

Frames designed and built to the relevant Australian Standard are deemed to comply with BCA requirements. Areas subject to extreme wind conditions (cyclonic) or areas subject to seismic activity are subject to separate Australian Standards that detail additional fixing and construction requirements.
Joints and connections

Joints and connections are closely linked to tie-down and bracing requirements and vary substantially between steel and timber framing systems. Accredited wall fabricators usually design and certify these aspects with details that suit their system.

Steel wall sections are usually screwed together on site. Multi-nail steel plate connectors for timber are fast, strong and cost effective.

Qualiﬁed professional carpenters and joiners can usually choose proprietary ﬁxing systems that will be approved by certiﬁers. It is critical that frame inspections by licensed, accredited certiﬁers are completed before the ﬁxing of linings or cladding. Bulk insulation, ﬂashings and condensation detailing are commonly inspected simultaneously.

Services

Lightweight framing systems generally simplify the installation of services through simple drilling to accommodate pipes and cables. Steel frames often include pre-notched openings that are simply removed.

Steel frames require cushioning grommets to protect cable insulation during installation and limit longer term damage to plumbing due to expansion and contraction or corrosion.

Care should be taken to ensure that trades do not weaken the structure by drilling near the edge (structural zone) of the stud. The need to centre services in frames can conﬂict with bulk insulation installation, and can result in the electrical cable capacity being de-rated. This often leads to compression of insulation or increased thermal bridging where gaps are left to meet electrical codes.

Advanced cabling solutions and circuit design can overcome this. Alternatively, externally ﬁxed foam insulation allows air space around cables. (see Cladding)

Finishes

Finish is generally determined by choice of cladding (see Cladding). In warmer climates, the frame is often exposed and painted (e.g. the classic Queenslander). Frames can also be expressed architecturally through clearly deﬁned joints or ﬁxing patterns.

Things to watch out for

With lightweight framing, the bracing and tie-down detailing must be designed and installed to appropriate wind loadings and seismic codes.

Material speciﬁc risks include:
• timber: condensation, rot and termite attack
• steel: corrosion, thermal bridging and related condensation issues.

References and additional reading

ACCEL acoustic predictions: www.accel.com.au
  - Eco priority guide: walls
  - Timber & wood products: preservatives, binders, ﬁxing
  - Thermal mass & its role in building comfort and energy efﬁciency

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## References and additional reading

<table>
<thead>
<tr>
<th>Reference</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>− 1999. Case study, Couran Cove.</td>
<td></td>
</tr>
</tbody>
</table>

## Authors

Principal author: Chris Reardon  
Contributing authors: Tom Davis, Paul Downton  
Updated by Chris Reardon, 2013