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The Seismic Resilience of Ancient Structures, Sri Lanka

A Scoping Review of Materials, Design Features, and Implications for Modern Researchers

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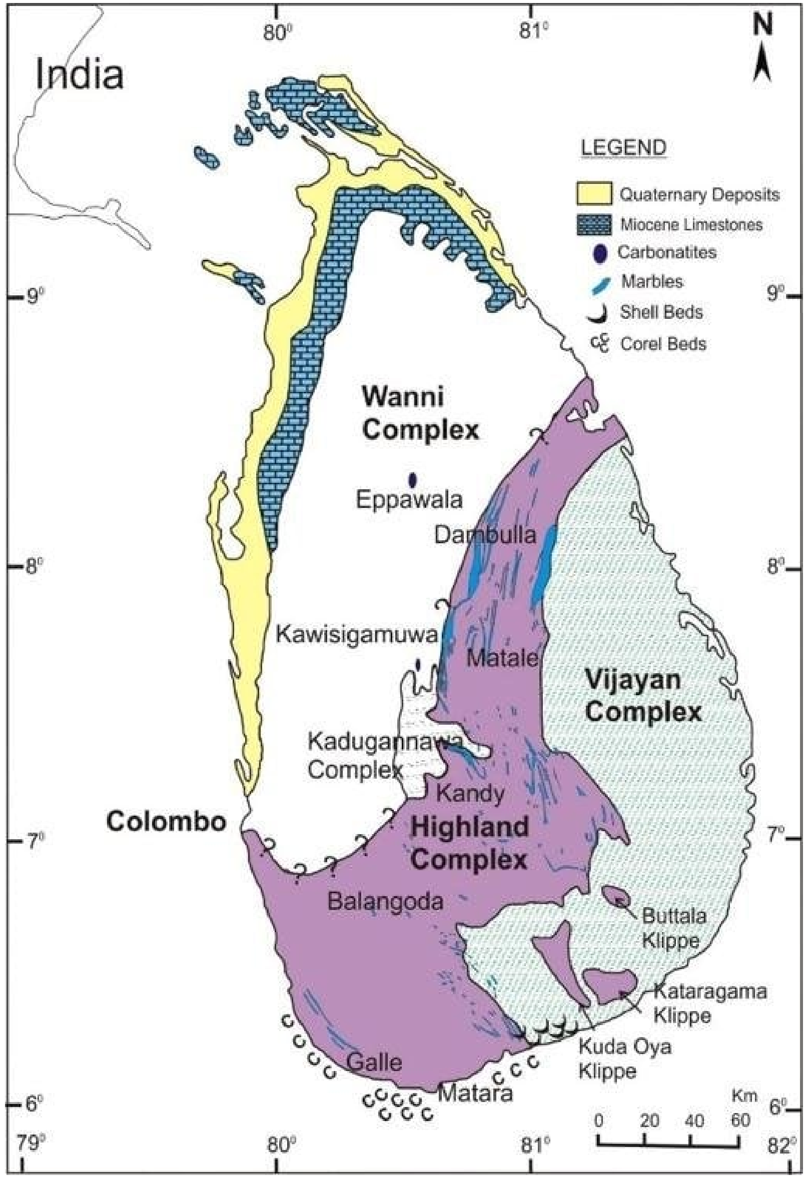
1. Introduction and Context

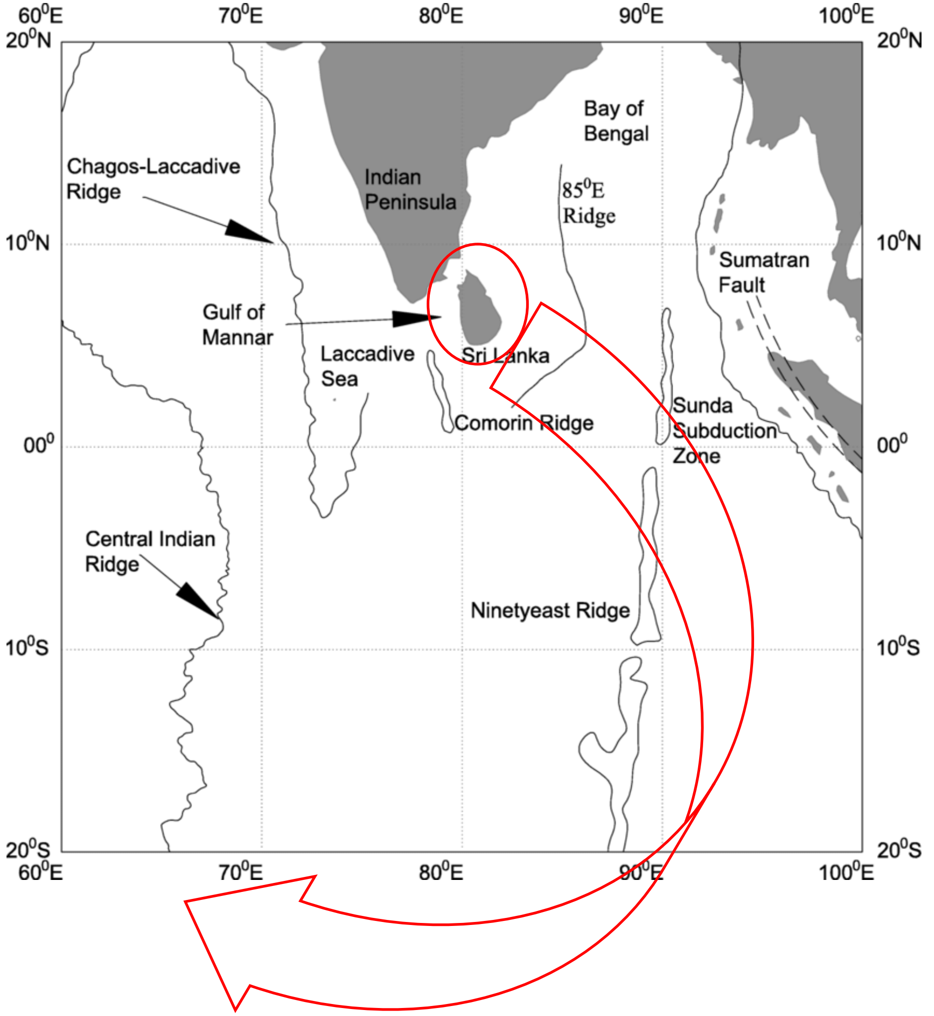
Challenge: Seismic Risk in Sri Lanka

- **Perception:** Sri Lanka is in a region of **low-to-moderate seismicity**.
- **Reality:** The Island faces a **non-negligible seismic risk**.
- **Historical: 1615 earthquake** (6.0 to 6.9 M, struck the western part of the island caused an estimated 2,000 casualties and severe structural damage) as a severe historical event.
- **Problem:**
  - Current **Unreinforced Masonry (URM)** buildings are widely recognized for **high vulnerability** to seismic activity.
  - The potential for **catastrophic failure** in these buildings poses a significant risk to life and property.

Sri Lanka Seismo-tectonic location (northern Indian Ocean)

- Major plate boundaries located 1000–1500 km away thus unlikely to produce direct threats of interplate EQ.
- Low-to moderate seismicity, faces a non-negligible seismic risk, underscored by historical events such as the 1615 EQ.





Generalized geological and tectonic map of Sri Lanka occurrences of marbles, carbonatites, limestones and other carbonate rocks. (Cooray, 1984).

Built over 2,000+ years ago-(UNESCO World Heritages)

Built over 2,000+ years ago during the Ancient Kingdom SL; represent major architectural and spiritual milestones of early Theravada Buddhism. Some constructions as far as around 3,000 BC.

- **Ancient 03 Buddhist Stupas of Sri Lanka –MRJ** Mirisawetiya, Ruwanweliseya and Jetavanaya deeply revered religious relics.
  - **Jetavanaya:** Massive brick structure Built in 2,000+ years ago, originally 122 meters (400 ft) tall, making it the **third-tallest structure in the entire ancient world**
  - **Surpassed only by the Giza pyramids** is also a UNESCO World Heritage Site.

Modern Unreinforced Masonry (URM) buildings are widely recognized for their high vulnerability, the island's ancient architectural heritage particularly monumental Sthupas has demonstrated remarkable longevity.

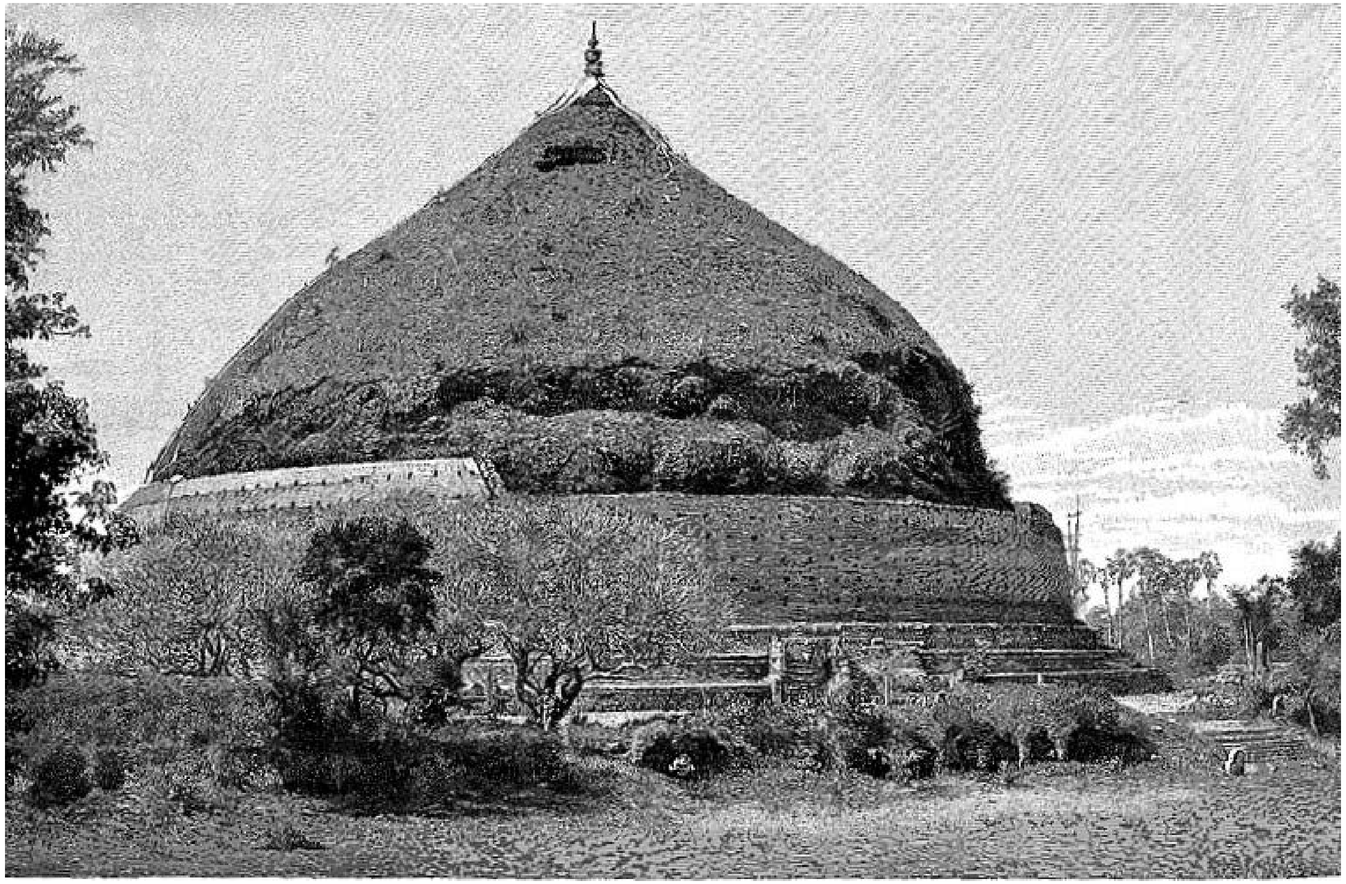
Collapsed unreinforced masonry building in Bhaktapur, Nepal following the Gorkha earthquake. *Source: Ben Mason, 2015*

Mirisaweti Sthupa (161 BC to 137 BC)- 2,180 years ago

Source: Ulrich von Schroeder, 1993

Ruwanwelisaya (Great Sthupa)- for Buddha's relics built in 140 BC (2,165 years ago)

The stupa is one of the world's tallest ancient monuments, standing at 103 m (338 ft) and with a circumference of 290 m (951 ft).



Ruwanwelisaya in 1891 Scribner's Magazine

Jetavanaya-UNESCO world heritage

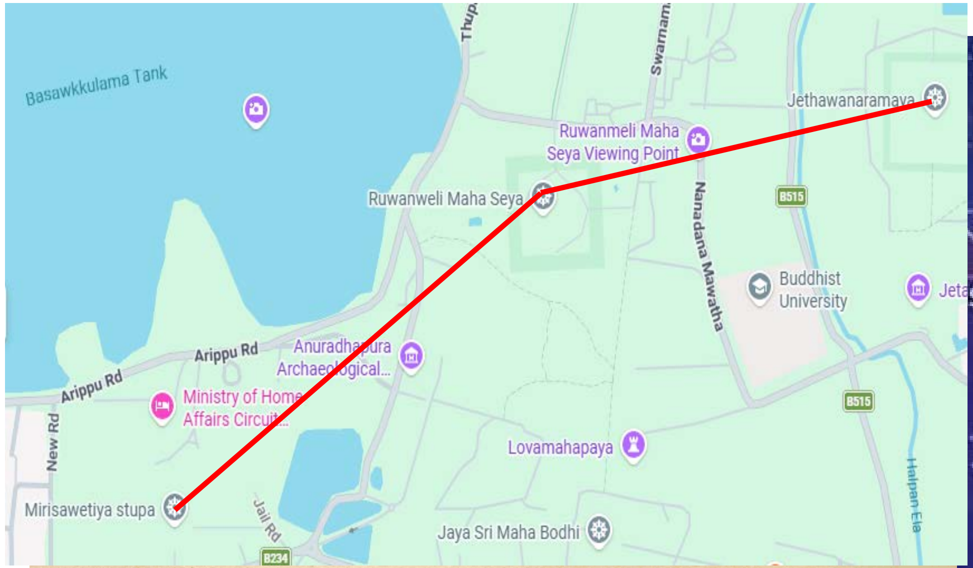
At 122 metres (400 ft), it was the ancient world's (when it was built in 273–301) 1,753 years ago) tallest structure and the third tallest structure in the world (only behind the two Great Pyramid of Giza and Khafre)

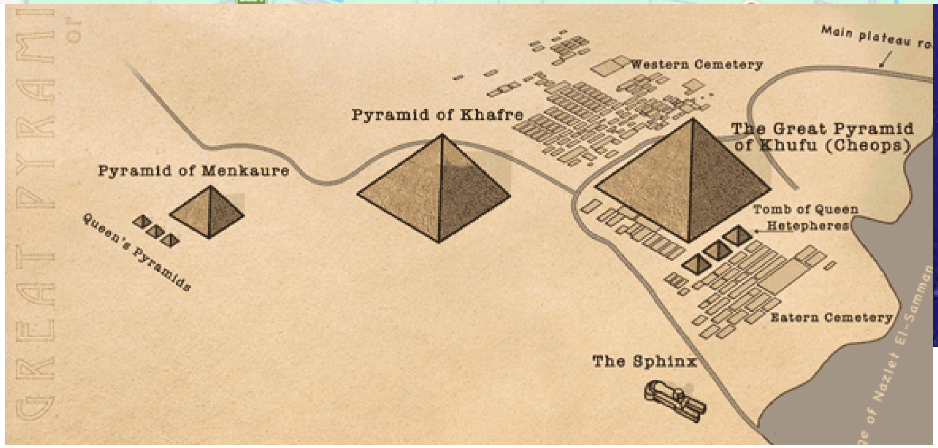
Source: Wikimedia, Bandara

A massive structure using 1600 stone pillars built in 161-131 BC called *Lovamahapaya* of which the remains today.

Source: amazinglanka.com

It is Noted, Ground layouts of the three massive stupas of Sri Lanka; MRJ (Mirisavatiya, Ruvanweliya and Jetavanaya) **three huge pyramids at the Giza plateau** of Egypt, conclusively **aligns with the three specific stars** (Alnitak, Alnilam Mintaka) in the belt of the star **constellation of Orion**.





2. Key Question

Two Masonries- Building types in SL

While modern URM buildings are fragile, SL **ancient architectural heritage** has shown remarkable **longevity**. Mainly two types of residential buildings practiced

- **masonry buildings with load bearing walls** made of sundried and / or fired bricks in urban areas and stone masonry with mud mortar in rural areas.
- **reinforced concrete moment resisting frame** buildings.

Inquiry: the inherent material properties and design features that underpin the **documented resilience** of these ancient structures.

3. Research Methodology
A Systematic Scoping Review

Objective: systematically map key concepts and synthesize evidence to understand the ancient structures' resilience.

Comprehensive Synthesis:

- **Archaeological Reports:** Historical and excavation data.
- **Materials Engineering Studies:** Analysis of ancient materials.
- **Computational Structural Analyses:** Modern modeling techniques (e.g., Finite Element Analysis).

Scoping review: systematically maps the key concepts and **synthesizes evidence on the seismic performance of these ancient structures**, investigating the inherent material properties and design features that underpin their documented resilience.

4. Key Finding

Not a Single Secret, but a Synergy

- The seismic resilience of these ancient structures is **not attributable to a single factor**.
- A key material advantage is the use of high-density brick and durable lime mortar with pozzolanic properties, which **exhibit greater flexibility and energy dissipation**.
- Structurally, the massive, dome-shaped form facilitates **optimal stress distribution**, while robust ring-beam foundations and the cohesive, monolithic behaviour of the entire assembly mitigate stress concentrations.
- Advanced computational models, including finite element analysis, suggest that these **integrated features would allow such structures to withstand** major seismic events, contrasting sharply with the brittle failure modes predicted for modern URM buildings.
- The findings demonstrate that ancient Sri Lankan builders achieved a level of **seismic resilience that surpasses that of many contemporary structures**.
- It is the result of a **synergistic combination** of two masterful approaches;
  - Superior Material Science
  - Sophisticated Structural Design

4.1 Material Advantage - The Brick & Mortar

Science of Ancient Materials

High-Density Dimension of Brick: More robust and stronger than typical modern bricks.

Durable Lime Mortar:

- Possesses **Pozzolanic properties** (reacts chemically to become stronger over time).

The Key Benefit:

- This combination exhibits **greater flexibility** than modern cement mortar.
- This allows for **energy dissipation** during ground shaking, absorbing seismic forces rather than fracturing.

4.2 Design - Form & Structure
Sophisticated Structural Engineering

Massive, Dome-Shaped Form:

- Facilitates **optimal stress distribution** throughout the structure.

Robust Ring-Beam Foundations:

- A "belt" around the base that acts as a strong, continuous tie.

Monolithic Behavior:

- The structure acts as a **single, cohesive unit**.

Overall Effect:

- These features work together to **mitigate stress concentrations** which are the primary cause of structural failure.

4.3 Evidence from Computational Modeling

Validating Ancient Wisdom with Modern Tech

Advanced Computational Models:

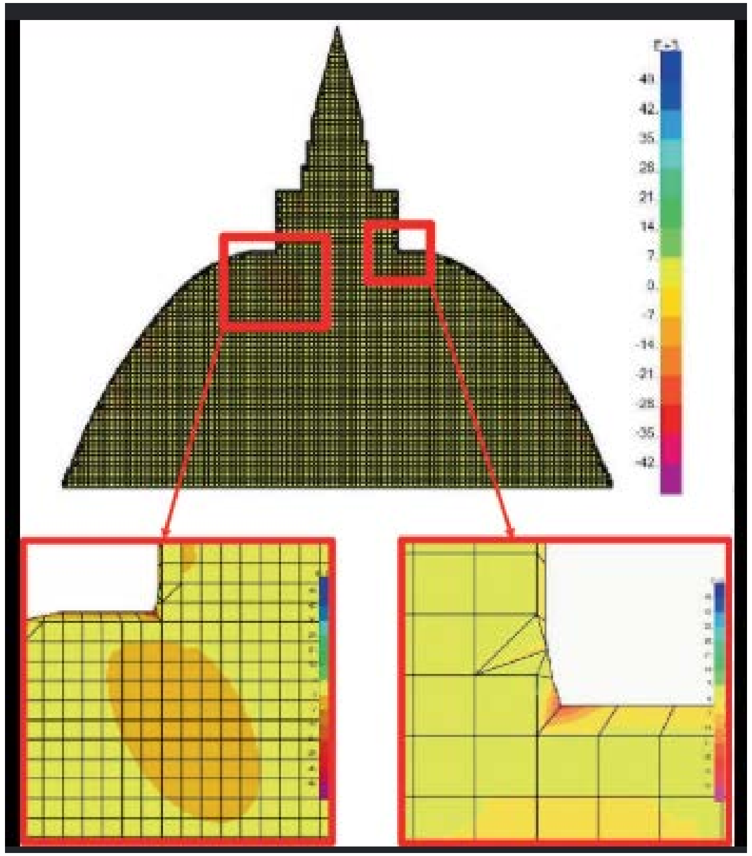
- Researchers use **Finite Element Analysis (FEA)** to simulate seismic events.

Results:

- The models suggest these integrated features would allow the structures to **withstand major seismic events**.

The Contrast:

- This predicted performance **contrasts sharply** with the **brittle failure modes** predicted for modern URM buildings (which would collapse suddenly and catastrophically).



Ref: Kulasiri, 2024

5. Conclusion and Significance

Understanding and adapting these traditional, durable techniques offers a crucial pathway for developing more resilient, context-appropriate construction practices and community preparedness in SL.

- **Traditional Engineering:** Ancient Sri Lankan builders (**2,180 years ago**) achieved a level of seismic resilience that surpasses that of many contemporary structures.
- **A Valuable Benchmark:** Preserving this architectural heritage provides a **field-tested benchmark** for modern engineers.
- **A Crucial Pathway:** for developing more resilient, context-appropriate construction practices.

6. Implications and Future Directions

Actionable Insights

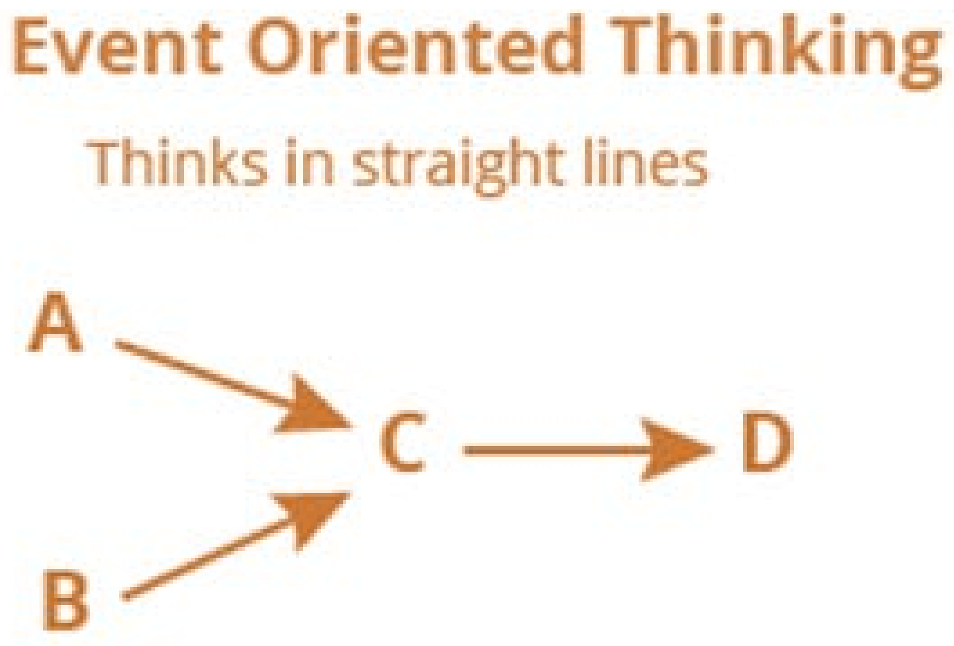
Informing Modern Construction: Adapt traditional techniques (e.g., using lime mortar with Pozzolans, designing for mass and form) to build safer structures.

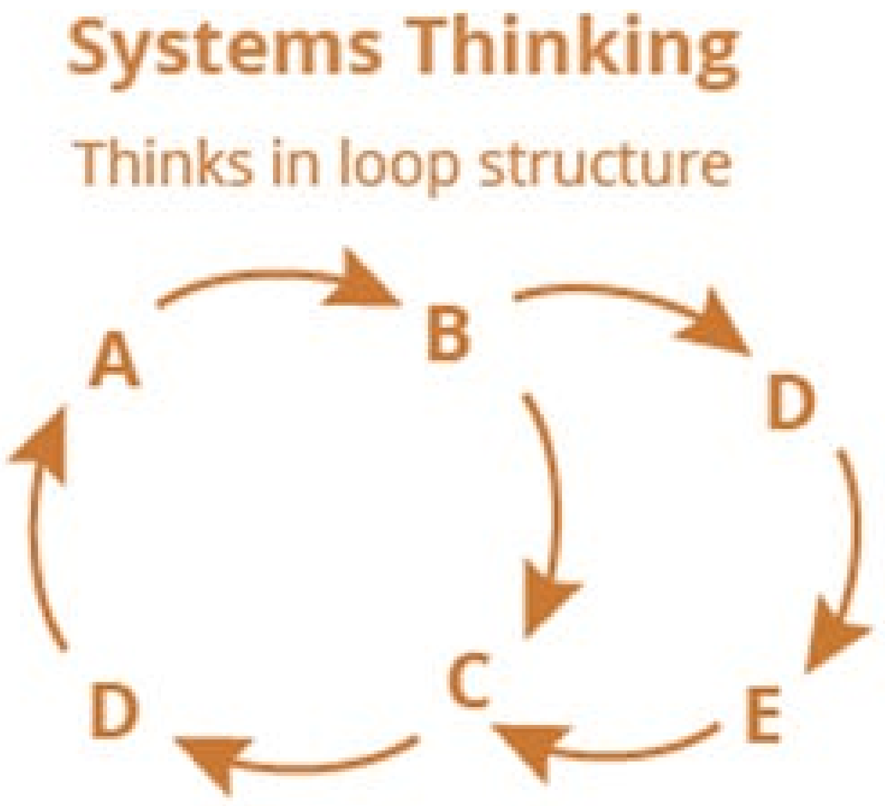
Enhancing Community Preparedness:

- Educating communities about resilient design.
- Using the evidence of ancient longevity to build trust in science-based retrofitting.
- Integrating these findings into building codes and disaster risk reduction strategies.

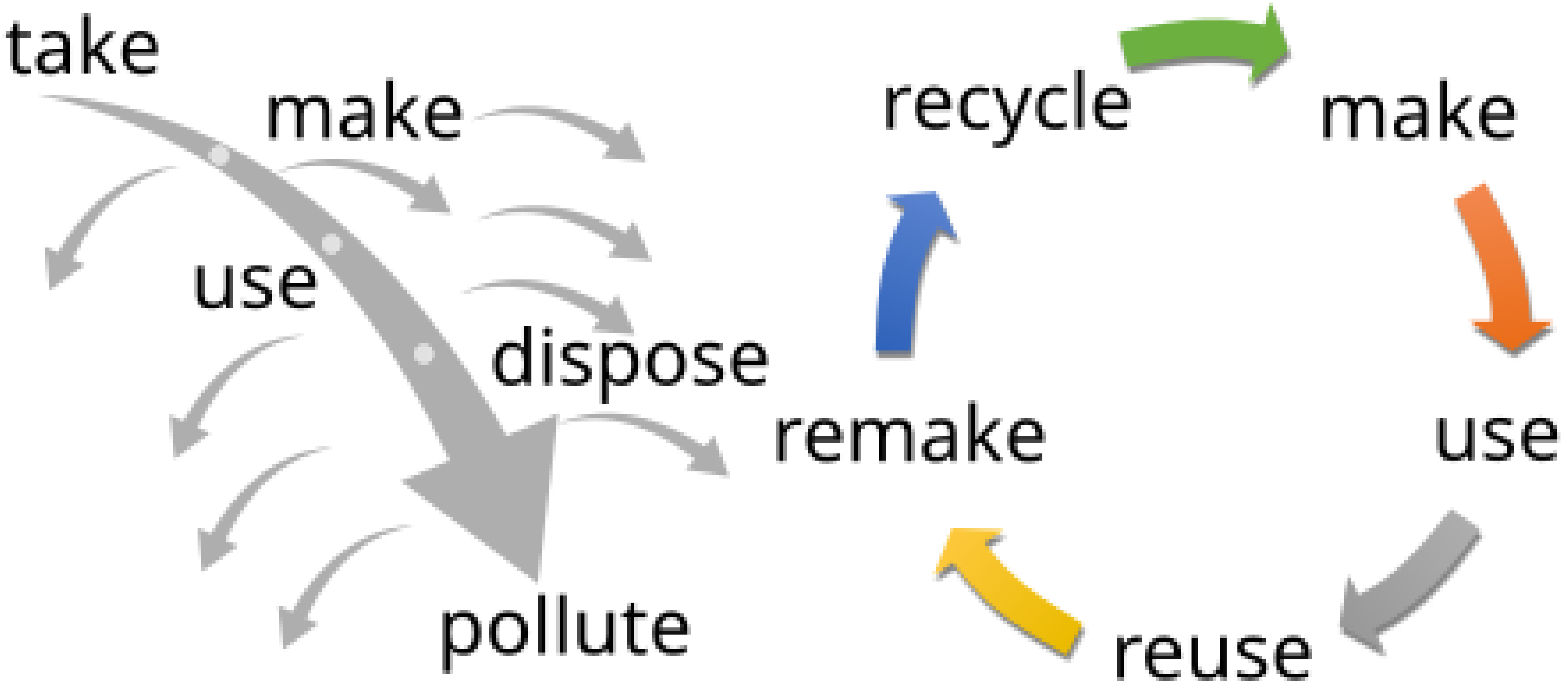
To strengthen Sri Lanka's national USAR system through INSARAG-aligned standards and verification, ensuring safe, effective, and coordinated rescue operations nationally and enabling future international deployments.

Linear and circular thinking





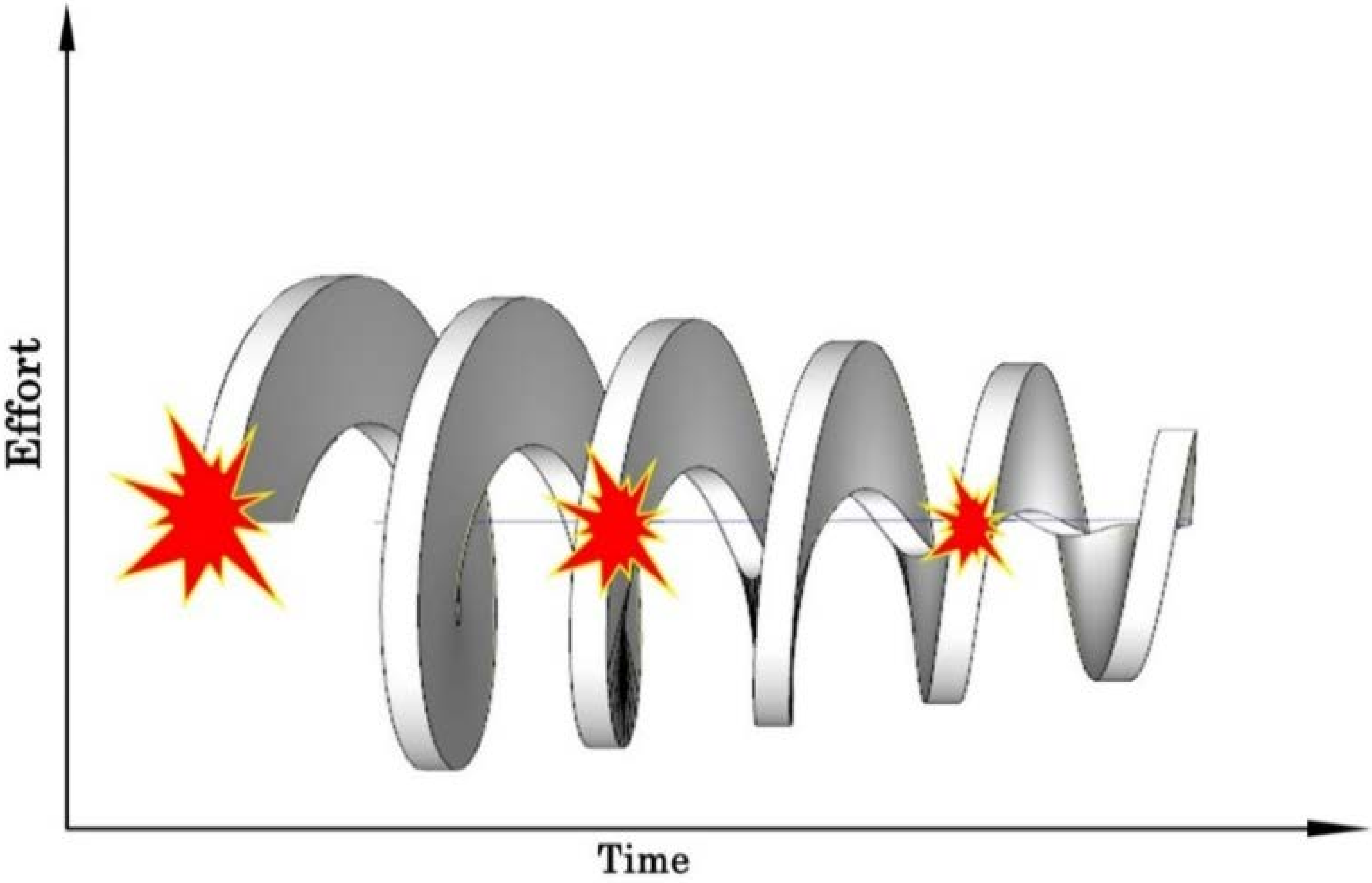
Linear and circular Modelling




Disaster
Emergency response
Warning
Disaster preparedness
Rehabilitation
Reconstruction
Development
Disaster prevention
Disaster mitigation

M&E Conceptualising the DRM (EQ.) phases Helix diagram

DRM efforts can diminish over time as risk decreases



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THANK YOU

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