GE1040 A Culture of Sustainability
AY 25/26 Sem 1 — github/omgeta

1. Unsustainable Development

Unsustainable development harms the ability of future generations to meet their needs due to the degradation of our climate, life-support systems and resources.

i. Global Environmental Indicators: Planetary boundaries have already been exceeded (climate change, biodiversity loss, nitrogen cycle).
ii. Stability Landscape: Ecosystems may lose resilience — once thresholds are crossed (valley basins), systems may not return to their original state.
iii. Changing Climate: We are living in a changing climate. We need to mitigate impacts on us and ecosystem, or otherwise become more adaptable

Ecological Footprint

Terminology:

i. Bioproductivity: amount and rate of production occuring in an ecosystem over a period of time.
ii. Biocapacity = Area × Biocapacity: quantifies nature's capacity to produce renewable resources, provide land for built-up areas and provide waste absorption services such as carbon uptake.
iii. Ecological Footprint (gha) = Population × Consumption/Person × Footprint Intensity: quantifies biological productive area needed for provision of renewable resources, or require absorption of CO_2 waste.
iv. Footprint and biocapacity can be ranked by countries, enabling them to learn from each other.
v. Ecological Deficit: ecological footprint>biocapacity (currently exceeded by 50%).

Earth Overshoot Day is the date when annual footprint exceeds annual biocapacity:

i. Occurs earlier each year (first at 1970)
ii. COVID-19 caused ecological footprint to contract
iii. #MoveTheDate: push overshoot to December via sustainable cities, resilient systems, etc.

Causes

Overpopulation due to exponential population growth:

i. 8.1b (2025) → 9.5b (2050) → 11b (2100)
ii. Pressure on land, soil degredation, and biodiversity
iii. Prior to Industrial Revolution, growth was resource-limited but now largely unchecked
iv. Various demands by billions for a comfortable life, but everyone should have the equal right to health

Unsustainable Resource Use:

i. Affluenza: oversumption in affluent societies
ii. Developing countries fixated on GDP as sole success metric ignoring environmental costs

Poverty links to environment in a downward spiral:

i. Direct reliance on food, water, fuel for survival
ii. Degenerate forests, soil, grasslands and wildlife causing environmental degradation
iii. Degraded environment further impoverishes people

Excluding Environmental Costs:

i. Market prices ignore externalities such as ecosystem loss, health impacts and pollution
ii. Ex. Timber companies pay to clear forests but not for environmental degradation and loss of habitat
iii. Ex. Fishing companies pay to catch fish but not for depletion of fish stocks
iv. Taxes and fines aim to fix this but not enough

Tragedy of the Commons

Tragedy of the commons is the overuse of a common property or free-access resource causing depletion for all.

i. Mentality of "If I do not use it, someone else will. The little bit I use or pollute doesn't matter".
ii. Solutions:
   - Responsible usage of shared renewed resources at rates well below sustainable yields
   - Convert open-access renewable resources to private ownership

IPAT Model

IPAT quantifies environmental impact as $I = P \times A \times T$ where P is population, A is affluence, T is technology:

i. Population: not dominant factor
ii. Affluence: $\frac{\text{Goods \& Services}}{\text{Person}}$ can harm through high consumption, pollution and resource wastage but also produce funding for innovative R&D (e.g. Denmark, India's ethanol-blended gasoline)
iii. Technology: $\frac{\text{Impact}}{\text{Goods \& Services}}$ reduces impact
iv. Ex.: Gasoline = cars × miles/car × gasoline/mile

Pollution

Pollution is the introduction of contaminants into the natural environment that adversely affects a resource.

i. Point Source: single, identifiable source (e.g. smokestack, drainpipes)
ii. Nonpoint Source: dispersed and difficult to identify (e.g. fertilizer and pesticide runoff into lakes - first flush effect after dryspell)

Health Effects:

i. Headache and Fatigue
ii. Respiratory Illness
iii. Cardiovascular Illness
iv. Cancer Risk
v. Nausea and Gastroenteritis
vi. Skin Irritation

Management Methods:

i. Cleanup (end-of-pipe): clean/dilute contaminants
   - Temporary; growth in consumption may offset pollution control tech
   - Often relocates pollutants to another area
   - Costly to clean dispersed pollutants
ii. Prevention (front-of-pipe): reduce/stop production

Environmental Viewpoints

Planetary Management:

i. View: We are apart from the rest of nature and can manage it to meet our increasing demands.
ii. Resources: We will not run out, due to our ingenuity and technology.
iii. Economy: Potential for economic growth is essentially unlimited.
iv. Success: Depends on how well we manage the earth's life-support systems for our benefit.

Stewardship:

i. View: We have an ethical responsibility to be caring stewards of the earth.
ii. Resources: We will probably not run out, but they should not be wasted.
iii. Economy: Encourage environmentally friendly economic growth and discourage harmful forms.
iv. Success: Depends on our managing the earth's life-support systems for our and nature's benefit.

Environmental Wisdom:

i. View: We are part of and totally dependent on nature, and nature exists for all species.
ii. Resources: Limited and should not be wasted.
iii. Economy: Encourage earth-sustaining economic growth and discourage earth-degrading forms.
iv. Success: Depends on learning how nature sustains itself, integrating them into how we think and act.

2. Principles and Practical Applications of Sustainability

Environmentally sustainable societies meet present needs without compromising future generations' own needs:

i. Without destroying the environment
ii. Without endangering the future welfare of the planet and its people
iii. In a just and equitable manner

Sustainability is the ability of Earth's natural systems, cultural systems and economies to survive and adapt to changing environmental conditions indefinitely. 3 Pillars:

i. Environment (ecological integrity)
ii. Economy (economic viability)
iii. Society (equity)

Sustainable Development Goals (SDGs)

UN Sustainable Development Goals (SDGs) were adopted in 2015 by 2500 scientists from 190 nations, providing a global framework to steer towards a safe and just operating space for society to thrive in until 2030:

1. No Poverty
2. Zero Hunger
3. Good Health and Well-being
4. Quality Education
5. Gender Equality
6. Clean Water and Sanitation
7. Affordable and Clean Energy
8. Decent Work and Economic Growth
9. Industry, Innovation and Infrastructure
10. Reduce Inequality
11. Sustainable Cities and Communities
12. Responsible Consumption and Production
13. Climate Action
14. Life below Water
15. Life on Land
16. Peace and Justice Strong Institutions
17. Partnerships to achieve the Goal

International Spillovers

Spillovers are transboundary negative impacts generated by one country on others, which can undermine their ability to achieve the SDGs, measured by Spillover Score. Types of spillovers:

i. Environmental: use of natural resources and pollution, including transboundary effects embodied in trade, and direct cross-border flows in air and water
ii. Economic/Financial/Governance: international development finance, unfair tax competition, banking secrecy, and labor standards
iii. Security: negative externalities such as arms trade and organized crime destabilizing poorer countries; positive spillovers include conflict-prevention and peacekeeping investments

Natural Capital

Natural capital (natural resources + natural services) refers to the stock of natural resources and ecosystem services that sustain human life :

i. Natural Resources: includes air, water, soil, land, life (biodiversity), nonrenewable resources, renewable energy and nonrenewable energy
ii. Natural Services: includes air purification, water purification, water storage, soil renewal, nutrient recycling, food production, conservation of biodiversity, wildlife habitat, forest renewal, waste treatment, climate control, population control and pest control
iii. Degradation of natural capital undermines long-term sustainability
iv. Preserving natural capital is essential for intergenerational equity

Sustainability Concepts

Shifting Emphasis:

i. Pollution cleanup → Pollution prevention
ii. Waste disposal → Waste prevention and reduction
iii. Species protection → Habitat protection
iv. Environ. degradation → Environ. restoration
v. Increased resource use → Less wasteful resource use
vi. Population growth → Population stabilization by decreasing birth rates
vii. Depleting and degrading natural capital → Protecting natural capital, living off bio-interest

Lessons from Nature:

i. Runs on renewable solar energy → Rely mostly on renewable solar energy
ii. Recycles nutrients and wastes (little waste) → Prevent/reduce pollution, recycle & reuse resources
iii. Uses biodiversity to maintain and adapt to environmental change → Preserve biodiversity by protecting ecosystem services, habitats and species
iv. Controls species' population size and resource use → Reduce births and wasteful resource use to prevent environmental overload, and depletion and degradation of resources

Challenges:

i. Depletion of finite resources (fossil fuels, soil, minerals, species)
ii. Overuse of renewable resources (forests, fish & wildlife, soil fertility, public funds)
iii. Pollution (air, water, soil)
iv. Inequity (economic, political, social, gender)
v. Species loss (endangered species and spaces)

Solutions:

i. Cyclical use of resources (emulate nature; 3R's)
ii. Safe reliable energy (conservation, renewable energy, subtitution, interim measures)
iii. Human well-being interests (health, creativity, learning, cultural and spiritual development)

Research & Development (R&D)

Examples of sustainability-oriented research and indigenous technology development:

i. Power Generation: Biogas integrated with waste management/Co-Gen systems
ii. Construction Materials: Local, non-toxic, reusable materials; water as material for thermal walls
iii. Water Supply: Rainwater harvesting for groundwater recharge and building cooling
iv. Water Treatment: Natural biomaterials for turbidity removal; UV disinfection from sunlight; fabric filtration for point-of-use treatment
v. Storm-water Management: Green roofs for runoff reduction, reduced energy use, and cooling effect
vi. Building Design: Passive solar design, right-sized homes, cost-effective ventilation, maximize storage and comfort with minimal energy

Green Roofs are intensive (thick substrate, shrubs/trees) or extensive (thin substrate, smaller plants):

i. Aesthetically pleasing
ii. Reduce storm-water runoff
iii. Reduce urban heat island effects
iv. Reduce air conditioning costs
v. Negate acid rain effects
vi. Reduce CO_2 impact
vii. Create habitats for certain plants and animals
viii. Cooling Effect: protects from solar radiation, stabilizes roof temperature, cools building interiors
ix. Water Quality: depends on substrate layer, vegetation type, fertilisation quality, roof age, surrounding area type, local pollution sources

Key Carbon Considerations:

i. Embodied: emissions from construction materials
ii. Operational: emissions from running processes

Case Study: NUS Sustainability Initiative

Current Practices:

i. Integrated into education, research, campus operations, and leadership
ii. Contributes directly to multiple SDGs such as climate action, clean energy, and sustainable cities

Future:

i. Driving sustainability via collaboration with other sectors (internal and external partners)
ii. Building climate resilience by linking research across climate, urban, economic, and social areas

Case Study: Punggol Digital District (PDD)

Current Practices:

i. 17 Green Mark Platinum and 3 Super Low Energy Buildings (e.g. Mass Engineered Timber with 98% lower embodied carbon)
ii. Smart Energy Grid: real-time data management optimisation saves 1,700 tonnes CO_2 annually; rooftop PV panels generate 3,000 MWh annually
iii. Open Digital Platform (ODP): collect and analyse environmental and building data to improve energy efficiency, reduce costs and minimise impact
iv. Digital Twin: real-time planning-simulation model
v. Centralised Cooling System: cooling towers with underground distribution reduce energy use by 30% and 3,700–4,000 tonnes CO_2 annually
vi. Carlite District: prioritises low-emission transport

Future:

i. Environmental Modelling
ii. Use of recycled materials for construction
iii. Fuel Cell System for Lifts
iv. Regenerative Lift converts motions into energy
v. Centralized Chutes for Recyclables
vi. "Develop an eco-town with a human settlement that enables its residents to live a good quality of life while using minimal natural resources."

Case Study: Singapore Story

Vision of "Clean, Green and Good Living Environment" for present and future generations, balancing economic development, social progress and environmental protection (strong commitment from the top).

Fundamental Principles:

i. Control pollution at source
ii. "Polluter Pays" principle
iii. Pre-empt and take early action
iv. Innovation and technology
   - Ex. Semakau Landfill as first man-made offshore landfill, Ulu Pandan NEWater Plant
v. Resource conservation
   - Ex. Waste recycling, energy efficient energy
vi. Environmental ownership
   - Ex. Involvment of 3P (private, pubic, people) with communication, engagement and empowerment

Key Strategies:

i. Integrated land-use planning and development control (e.g., Singapore River clean-up)
ii. Environmental infrastructure (e.g., integrated solid waste; water and wastewater treatment)
iii. Environmental legislation and enforcement (pragmatic, progressive controls)
iv. Environmental monitoring (assess level of pollution, track trends, inform standards and planning)
v. Environmental education (instil awareness via campaigns, training, dialogues)

Future Challenges:

i. Small tropical island, high population density, limited natural resources
ii. Rising consumerism and environmental expectations; need to sustain standards

3. Circular Economy

Circular economy is a regenerative system where resource input, waste, emissions, and energy leakage are minimised by slowing, closing, and narrowing resource loops.

i. Replaces the end-of-life concept with long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling
ii. Regenerate natural systems by returning valuable nutrients to ecosystems
iii. Supports economic, environmental, and social dimensions of sustainable development
iv. Mimics nature's cyclical systems

Economy Progression:

i. Linear Economy: take → make → dispose (single-use, wasteful)
ii. Recycling Economy: partial recovery through recycling but still wasteful
iii. Circular Economy: design for closed loops, resources kept in circulation, waste designed out

Energy and Matter

High-quality energy is concentrated, good for useful work. Low-quality energy is dispersed, bad for useful work.

Three Big Ideas:

i. There is no "away": matter cannot be destroyed, only converted (Law of Conservation)
ii. Cannot get something for nothing; cannot get out more energy than in (1st Law of Thermodynamics)
iii. Cannot break even; energy conversion from one form to another reduces energy quality or less usable energy (2nd Law of Thermodynamics)

Economy Types:

i. High-throughput economy: unsustainable, high-waste, promotes pollution
ii. Low-throughput economy: matter-recycling and reuse; mimics nature and reduces pollutants but may be insufficient for growing populations

Industrial Symbiosis

Industrial symbiosis is a business relationship focused on sharing resources between industrial facilities/companies where wastes or byproducts from one become raw materials for another.

i. Subset of Industrial Ecology: shift from linear to cyclical (closed-loop) systems
ii. Mutually beneficial cooperation which reduces environmental impact while improving business competitiveness
iii. Key enabling business model for advancing the move to a circular economy
iv. Ex. Kalundborg, Denmark: cooperation among 8 industries sharing energy, water, and materials

Applications and Innovations

i. Bioplastics: key enabler of low-carbon circular economy; allow closed resource cycles and cascading reuse especially when being reused or recycled
ii. Design for longevity: durability, easy repair, remanufacturing
iii. Closed resource cycles: minimize virgin resource extraction via reuse and recovery
iv. Resource Recovery: convert waste streams into valuable resources (e.g., waste-to-energy, nutrient recovery, material cascading)

4. Sustainable Urbanization

Urbanization is inevitable as societies advance, but it poses significant environmental and social challenges. Sustainable cities aim to balance growth with ecological integrity, equity, and efficiency.

i. $>$ 50% of the world's population lives in cities, with further growth projected esp. developing countries
ii. Urban living $\rightarrow$ higher literacy, education, health, social services, cultural and political participation.
iii. Trends:
   - Proportion of urban global population growing
   - Number and sizes of urban areas mushrooming
   - Rapid increase in urban populations in developing countries
   - Urban growth slower in developed nations
   - Increasing poverty and inequality (75% of cities more unequal now than 20 years ago)

Disadvantages of Urbanization:

i. Unsustainable systems
ii. Lack of vegetation
iii. Water problems
iv. Pollution and health problems
v. Noise pollution
vi. Climate and artificial light
vii. Urban heat island
viii. Light pollution

City Expansions:

i. Compact Cities: Limited land area with high population density, thus growing vertically. Most people get around by walking, biking or public transport.
   - Ex:"" Hong Kong, Singapore, Tokyo
ii. Dispersed Cities: Ample land area available for outward expansion. Residents mostly depend on motor vehicles for transportation.
   - Ex: Australia, Canada, United States

Urban Sprawl

Urban sprawl is the uncontrolled, low-density outward expansion of cities into surrounding undeveloped or agricultural land, often characterised by low-density housing, single-use zoning and increasing reliance on private automobiles.

Causes:

i. Prosperity
ii. Ample and Affordable Land
iii. Automobile
iv. Cheap Gasoline
v. Poor Urban Planning

Problems (Natural Capital Degradation):

i. Land and Biodiversity: loss of cropland, forests, grasslands, wetlands and habitats
ii. Water: increased use/pollution of surface and groundwater, runoff and flooding, decreased natural sewage treatment
iii. Energy, Air and Climate: increased energy waste, air pollution, greenhouse gas emissions
iv. Economic: decline of downtown business districts, increased unemployment in central, loss of tax base in central

Regulating:

i. Smart Growth: policies promoting compact, high-density, mixed-use development with access to mass transit
ii. Greenbelts: surrounding large cities with open space for recreation, forestry, or sustainable uses
iii. Urban Growth Boundaries: strict limits beyond which urban development is prohibited
iv. Cluster Development: concentrate high-density housing on part of land while preserving shared open space on the rest of the land (often 40-50%)
v. Satellite Towns: smaller metropolitan areas outside the main city, reducing pressure on the core

Megacities

Megacities are metropolitan regions with populations exceeding 10 million people. They represent areas of high risk due to their complexity, scale, and vulnerability to environmental, economic, and social stresses.

i. Growth: By 2030, 41–53 megacities are projected worldwide. Asia alone is expected to host 30 megacities by 2025
ii. Sustainability Risks:
   - Rapid urban expansion without adequate planning drives resource depletion
   - Environmental degradation and loss of ecosystem services
   - Intensified greenhouse gas emissions from dense populations

Challenges:

i. Enormous demand for water, energy, waste management, and housing
ii. High risks of congestion, pollution, and infrastructure strain
iii. Extreme levels of poverty, social inequality, and vulnerability
iv. Fragmentation across economic, societal, and geopolitical dimensions

Solutions:

i. Promote resource efficiency through policy (e.g., compact cities, smart growth)
ii. Invest in sustainable infrastructure, mass transit, and renewable energy
iii. Develop strong institutional frameworks for governance and resilience
iv. Encourage inclusive urban planning to reduce inequality

Sustainable City Models

Environmentally Sustainable Cities:

i. Centralize the population within a given area
ii. Use renewable energy as much as possible
iii. Build and design people-oriented cities
iv. Use energy and matter efficiently
v. Prevent pollution and reduce waste
vi. Recycle, reuse, and compost
vii. Protect and encourage biodiversity
viii. Promote urban gardens and farmers markets
ix. Zone for environmentally stable population levels

Eco-cities model self-reliant resilient ecosystems:

i. Includes inhabitants and their ecological impacts
ii. Focus: eliminate carbon waste, run on 100% renewable energy
iii. Goal: incorporate environment into the city, reduce poverty, higher population densities, improve health

Smart cities use information and communication technologies:

i. Focus: increase operational efficiency, share information with public
ii. Goal: improve quality of government services and citizen welfare

Case Study: Vauban, Freiburg (Germany)

Current Practices:

i. Connected, efficient, green transport: trams near every home, pedestrian and bicycle paths, trains every 7.5 minutes with subsidised tickets
ii. Combined Heat and Power (CHP) plant fueled by woodchips for district heating
iii. Buildings designed to low-energy and positive-energy standards
iv. Anaerobic digestion of organic waste: ecological sewage treatment from household waste creates biogas for cooking
v. Green infrastructure: 600 hectares of parks, 3,800 garden plots, and strong local food economy of farmships, wineries, butcheries, bakeries, etc.
vi. Renewable energy production encouraged with federal tax credits and regional utility subsidies

Case Study: Stockholm, Sweden

Current Practices:

i. Green roofs bind rainwater, solar cells convert solar energy and heat water
ii. Ecological fashion for environmentally aware
iii. Household refuse is sucked into automatic underground waste collection systems
iv. Heat exchangers in water treatment
v. Street rainwater is treated locally and flows into lakes instead of treatment plants
vi. Combustible waste is used for district heating and electricity; organic waste turned into biogas
vii. Low-flushing toilets and tap aerators reduce water consumption by half

Case Study: Singapore Green Plan 2030

Aims:

i. City in Nature: plant 1 millon more trees by 2030, develop green spaces, adding new 1000ha by 2035
ii. Green Government: public sector leads sustainablty
iii. Sustainable Living: strengthen green efforts in schools, development of nationwide car-lite transport system, reduce waste to landfill per capta and household water consumption
iv. Energy Reset: clear-energy vehicles and EV-ready towns, achieve 80% gren buildings by 2030, reduce energy consumtpion in HDBs, 4× solar energy
v. Green Economy: incentivise sustainable industries, develop carbon services, seek investments in sustainability, and create jobs
vi. Resilient Future: safeguard coastlines against rising sea levels, improve food security, reduce urban heat

Case Study: CO_2 Accounting in China

Findings:

i. Shanghai: highest per capita GDP and consumption-based CO_2 emissions
ii. Beijing & Tianjin: similar per capita consumption-based emissions despite Beijing's local per-capita territorial emissions
iii. Chongqing: lowest per capita consumption-based emissions due to lower development
iv. Capital formation is the largest contributor to emissions, driven by rapid growth, infrastructure, and government policy
v. Household consumption ranks second, with a smaller share than in developed countries
vi. Beijing has large government expenditure as capital
vii. Imports outweigh exports in embodied emissions, dominated by construction
viii. Food imports are high in Shanghai, Beijing, and Tianjin, but minimal in Chongqing
ix. Emissions rise with infrastructure demand, transport networks, and higher incomes

5. Carbon Management

Carbon management in built environment is critical to reduce greenhouse gas emissions, since the building and construction sector accounts 36% of final energy use and 39% of energy- and process-related CO_2 emissions in 2018.

i. Operational Carbon: emissions from building use such as heating, cooling, lighting, and appliances.
ii. Embodied Carbon: emissions from materials and construction, including extraction, manufacturing, transport, and assembly.
iii. Life Cycle Stages: raw materials, transport, manufacturing, construction, operation, and end-of-life (reuse, recycling, landfill, incineration).
iv. Footprint: the total carbon impact is the sum of embodied and operational emissions.

Energy-Efficient Buildings

Passive Design reduces energy demand:

i. Natural Ventilation
ii. Sunlight Shading and Daylighting
iii. Dynamic Facade

Active Design improves system efficiency:

i. Energy Efficient Chiller
ii. Energy Recovery System
iii. Evaporative Cooling
iv. LED Lights

Smart Energy Management uses technology to monitor, control, and optimize energy use:

i. Intelligent Building Management System (BMS)

Renewable Energy Integration generates power on-site, often combined with other strategies to maximise energy generation:

i. Photovoltaic Panels
ii. Wind Energy
iii. Tidal Energy
iv. Geothermal Energy

Types of Buildings:

i. Zero Energy Buildings (ZEB): produce as much energy as they consume annually.
ii. Super Low Energy Buildings (SLEB): operate with much lower energy use than conventional buildings.
iii. Positive Energy Buildings (PEB): generate surplus energy that can be stored, shared, or sold.

Surplus Energy from PEBs can be:

i. Stored: in batteries for later use
ii. Shared/Sold: exported to the grid or shared with others; a Renewable Energy Certificate (REC) is a tradeable proof of 1 MWh of renewable energy fed into the grid
iii. Integrated: in smart grids for efficient distribution

Design for Manufacture and Assembly (DfMA)

Fundamentals of DfMA:

i. Simplifies design for efficient manufacture and assembly.
ii. Identifies and eliminates waste and inefficiency.
iii. Enables end-of-life pathways such as reuse and recycling through design for disassembly.

EOL Scenarios:

i. Landfill: frame is disposed, contributing to waste and environmental impact
ii. Downcycle: frame is recycled into lower-value products, extending life but reducing utility
iii. Incinerate: frame is burned, generating energy but releasing emissions and reducing material recovery
iv. Re-use: frame is directly reused in new projects, preserving value and minimising waste

Implementation:

i. Minimize number of components
ii. Modular construction (e.g. prefab units, modules)
iii. Simplify joints (e.g. plug-in connections)
iv. Top-down vertical assembly with self-aligning parts

Prefabricated Prefinished Volumetric Construction (PPVC)

PPVC modules are manufactured and finished off-site before being transported and assembled on-site.

i. Improves construction productivity and efficiency
ii. Ensures higher quality through controlled factory conditions
iii. Reduces dust, noise, and on-site disruption
iv. Requires fewer workers on-site, enhancing safety
v. Speeds up project timelines through parallel off-site fabrication and on-site preparation

Reducing Embodied Carbon

Concrete and steel are major sources of embodied emissions. Reductions can be achieved through:

i. Material substitution:
   - GGBS - 30–50% replacement of cement
   - PFA - 15–30% replacement of cement
   - RCA - 10% replacement (coarse fraction)
   - WCS - 10% replacement (fine fraction)
ii. Optimizing material use via efficient structural design
iii. Procuring low- or zero-carbon alternatives
iv. Designing for re-use and recycling at end-of-life

Life Cycle Assessment (LCA) of Materials:

i. Embodied carbon is released at the start of a building's life, "locking in" emissions for decades
ii. Early-phase reductions are critical to avoid long-term carbon lock-in
iii. Operational carbon accumulates over the use phase and can be reduced through retrofits and energy efficiency upgrades

6. **Air Quality**
7. **Climate Change**
8. **Nonrenewable Energy**
9. **Renewable Energy**
10. **Sustainable Water Resources**
11. **Zero Waste**
12. **Environmental Hazards and Health**