



# **SUSTAINABILITY IN ENGINEERING DESIGN**

## **(24CV306B)**

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# Syllabus

## Module 2:

Design process as teamwork - Forming design groups, Group dynamics, Setting goal and scope - Assigning the design problem, Goal of the design, Design scope, Defining value streams, Sustainability constraints - Guiding principle for sustainable design, People, Planet, Profit/Prosperity, Required domain knowledge partner and stakeholder identification, Design synthesis - Integral synthesis, Generation of solutions, Risk assessment and mitigation by research and development, Case studies

# Design Process



# Design Process

- In modern engineering practice, design is **not an individual activity** — it is a **team-based process** involving professionals from multiple disciplines.
- The concept of **teamwork in design** is vital for **sustainable engineering**, where social, environmental, and economic factors must be balanced.
- A **design team** collaborates to create solutions that are **technically sound, cost-effective, environmentally responsible, and socially acceptable**.

# Design Process

## The Concept of Team-Based Design

- **Team-based design** integrates the knowledge and expertise of various individuals to achieve common project goals.
- It involves **collaborative planning, brainstorming, decision-making, and evaluation.**



# Design Process

## Typical members include:

- Civil engineers (structural, transportation, environmental)
- Architects
- Mechanical/electrical engineers
- Urban planners
- Environmental scientists
- Project managers
- Stakeholders and end-users

# Design Process

## Importance of Teamwork in Sustainable Design

- **Complexity of modern projects** – Sustainability involves multiple parameters like energy, materials, waste, and life-cycle cost that no single engineer can handle alone.
- **Interdisciplinary integration** – Combines expertise from different fields to achieve holistic solutions.
- **Innovation enhancement** – Diverse perspectives lead to creative and sustainable solutions.
- **Risk reduction** – Shared decision-making reduces errors and improves reliability.
- **Stakeholder inclusion** – Public participation and user feedback improve social acceptance.
- **Efficient resource use** – Shared ideas and collaborative efforts minimize duplication and waste.

# Design Process

## Structure of a Design Team

- A **design team** is organized hierarchically or collaboratively depending on the project.

Role	Responsibility
Project Manager / Design Leader	Oversees team performance, ensures deadlines and quality.
Design Engineers	Develop technical details (structural, environmental, etc.).
Sustainability Coordinator	Ensures eco-friendly design practices and compliance.
Analysts (Cost, Risk, Life Cycle)	Evaluate cost-benefit, environmental impact, and risk management.
Drafters / CAD Technicians	Prepare detailed drawings and design documentation.
Stakeholder Representatives	Bring user, community, and client perspectives.

# Design Process

## Forming Design Groups – Step-by-Step Process

### Step 1: Identify Project Objectives

- Define **scope, sustainability goals, and expected outcomes.**
- Example: For a green building project — reduce energy consumption by 30%, use recycled materials, and minimize waste.

### Step 2: Identify Required Expertise

- Based on project scope, list disciplines required (civil, environmental, electrical, etc.).
- Select experts with relevant technical and sustainability experience.

# Design Process

## Forming Design Groups – Step-by-Step Process

### Step 3: Team Formation

- Choose members based on:
  - **Technical competence**
  - **Communication skills**
  - **Problem-solving ability**
  - **Commitment to sustainability**
- Establish a **diverse mix** of professionals, including experienced engineers and young innovators.

# Design Process

## Forming Design Groups – Step-by-Step Process

### Step 4: Define Roles and Responsibilities

- Assign clear roles to avoid overlap.
- Document in a **Team Charter** specifying objectives, milestones, and communication flow.

### Step 5: Establish Communication and Collaboration Channels

- Set up meetings, digital collaboration tools (like **BIM, AutoCAD 360, Google Workspace**).
- Promote **open communication** and **feedback culture**.

# Design Process

## Forming Design Groups – Step-by-Step Process

### Step 6: Conflict Resolution and Decision-Making Strategy

- Define protocols for decision-making (consensus, voting, or leader-driven).
- Use negotiation, mediation, or compromise methods to resolve disputes.

### Step 7: Monitoring and Evaluation

- Regularly assess progress using **Key Performance Indicators (KPIs)** related to time, cost, quality, and sustainability.
- Conduct **peer reviews** and **post-design evaluations**.

# Design Process

## Characteristics of an Effective Design Team

- **Shared Vision:** Common sustainability and performance goals.
- **Mutual Respect:** Value every member's input.
- **Open Communication:** Continuous feedback and transparency.
- **Diversity of Skills:** Mix of technical and creative minds.
- **Strong Leadership:** Guides the team while encouraging participation.
- **Adaptability:** Flexible to changes and new information.
- **Commitment to Sustainable Outcomes:** Decision-making aligned with environmental and social responsibility.

# Design Process

## Tools and Techniques Supporting Team-Based Design

- **Building Information Modelling (BIM)** – Enables collaborative design and real-time data sharing.
- **Life Cycle Assessment (LCA)** – Assists in evaluating environmental impact collaboratively.
- **Design Thinking Framework** – Promotes human-centered and sustainable problem-solving.
- **Digital Collaboration Platforms** – MS Teams, Slack, Asana, Trello for project coordination.
- **Value Engineering Sessions** – Team discussions to improve design efficiency and sustainability.

# Design Process

## Challenges in Forming and Managing Design Teams

- **Communication Barriers** – Between disciplines or remote teams.
- **Conflicting Priorities** – Budget vs sustainability goals.
- **Unequal Contribution** – Some members dominating, others passive.
- **Lack of Sustainability Awareness** – Engineers may lack green design knowledge.
- **Coordination Complexity** – Especially in large-scale projects.
- **Cultural and Personality Differences** – Affect teamwork and decision-making.

# Design Process

## **Solutions for the challenges:**

- Conduct orientation programs on sustainability.
- Use structured communication tools.
- Encourage inclusiveness and feedback mechanisms.

# Design Process

## Case Example: Sustainable Building Design Team

- **Project:** Green Office Complex
- **Team Composition:**
  - Civil Engineer – structural design
  - Architect – sustainable building envelope
  - Mechanical Engineer – HVAC and energy systems
  - Environmental Engineer – waste & water management
  - Project Manager – scheduling and budgeting
  - Sustainability Expert – LEED/BREEAM certification



# Design Process

## Case Example: Sustainable Building Design Team

- **Project:** Green Office Complex
- **Outcome:**
  - Achieved 40% energy savings
  - Used 60% recycled materials
  - Zero discharge wastewater management

# Design Process

## GROUP DYNAMICS

- **Group dynamics** refers to the **interactions, behaviors, and relationships** among members within a team.
- It determines **how well a design group functions** — including communication, decision-making, motivation, and conflict management.
- In sustainable design, effective group dynamics are essential to ensure the project's **triple bottom line goals (environmental, social, and economic)** are met.

# Design Process

## Elements of Group Dynamics

Element	Description
Communication	Exchange of ideas, data, and feedback openly and clearly.
Cohesion	Degree to which members feel connected and committed to team goals.
Leadership	Direction, coordination, and motivation provided by the leader.
Decision-making	Process of choosing solutions collectively and rationally.
Conflict resolution	Managing disagreements constructively.
Trust and Respect	Essential foundation for collaboration and information sharing.
Participation	Equal involvement of all members to maintain balance and creativity.

# Design Process

## Stages of Group Development (Tuckman's Model)

- **Forming** – Team members meet, understand project objectives, and explore roles.
- **Storming** – Differences arise; conflicts about responsibilities or methods may occur.
- **Norming** – Common rules, work processes, and relationships stabilize.
- **Performing** – Team functions effectively with strong collaboration and focus on sustainability goals.
- **Adjourning** – Project completion and disbanding, with reflection and evaluation.

# Design Process

## Stages of Group Development (Tuckman's Model)

### Example:

In a green infrastructure project, engineers and architects initially debate design priorities (storming), but later align on energy efficiency and community acceptance (norming → performing).

# Design Process

## Importance of Healthy Group Dynamics

- **Promotes innovation** – Open idea sharing encourages creative sustainable solutions.
- **Improves efficiency** – Minimizes duplication and confusion.
- **Enhances motivation** – Members feel valued and responsible.
- **Reduces conflict** – Clear roles and respect lead to smoother cooperation.
- **Supports sustainability** – Integrates environmental and social thinking from diverse experts.

# Design Process

## Techniques for Managing Group Dynamics

- **Regular team meetings** to track progress.
- **Team-building exercises** to build trust.
- **Role clarity** through written agreements.
- **Active listening** during discussions.
- **Feedback loops** and open communication culture.
- **Conflict management** via consensus-building.
- **Encouraging inclusion** of all viewpoints.

# Design Process

## SETTING GOALS

- A **goal** is a clearly defined **desired outcome** that guides the design team's direction.
- In sustainable engineering, goals ensure that **environmental, social, and economic objectives** are embedded throughout the design process.

# Design Process

## Types of Goals in Sustainable Design

Type of Goal	Focus Area	Example
Environmental Goals	Reduce resource and energy consumption	“Reduce water usage by 40% through rainwater harvesting.”
Economic Goals	Cost efficiency and life-cycle performance	“Minimize construction cost by optimizing material usage.”
Social Goals	Community, safety, and livability	“Design accessible walkways for differently-abled people.”
Technical Goals	Performance, durability, safety	“Ensure structural stability for 100-year design life.”

# Design Process

## SMART Goals Framework

Parameter	Meaning	Example
S – Specific	Clear and precise	Reduce concrete waste by 20%.
M – Measurable	Quantifiable	Monitor energy use in kWh/month.
A – Achievable	Realistic based on resources	Install solar panels on 70% of roof area.
R – Relevant	Aligned with sustainability vision	Supports green certification.
T – Time-bound	Defined timeline	Achieve by project completion date.

# Design Process

## Process of Setting Goals

- **Identify Stakeholder Needs** – Understand client, user, and environmental expectations.
- **Evaluate Constraints** – Budget, technology, regulations, site limitations.
- **Define Sustainability Priorities** – Choose focus areas like energy, waste, water, mobility, etc.
- **Document Clear Goals** – Include measurable indicators (KPIs).
- **Review and Approve Goals** – Team and stakeholders validate feasibility.
- **Communicate to All Members** – Everyone must align to avoid misdirection.

# Design Process

## Importance of Goal Setting

- Provides **direction** to the team.
- Facilitates **decision-making** and **resource allocation**.
- Enables **performance tracking** and accountability.
- Promotes **integration of sustainability principles**.
- Encourages **collaborative motivation** and shared purpose.

# Design Process

## SCOPE

- The **scope** of a design project defines the **boundaries, extent, and deliverables** of the work to be performed.
- It specifies **what is included and what is excluded** in the project — ensuring clarity and control.
- In sustainable design, the scope must clearly address **environmental performance, social benefits, and economic viability**.

# Design Process

## Components of Project Scope

Component	Description
Project Objectives	Overall intent and outcomes to be achieved.
Deliverables	Tangible outputs – reports, drawings, prototypes, etc.
Design Boundaries	Physical, technical, and operational limits.
Sustainability Targets	Specific environmental/social/economic goals.
Constraints	Budget, time, legal, and resource limitations.
Assumptions	Factors considered true for planning.
Stakeholders	Parties involved – clients, users, regulatory agencies.

# Design Process

## Steps in Defining Project Scope

- **Understand the Project Context**
  - Analyze client requirements, site conditions, regulations, and sustainability mandates.
- **Conduct Preliminary Studies**
  - Environmental impact assessment, resource availability, and social impact analysis.
- **Develop Scope Statement**
  - A formal document describing project boundaries, objectives, and deliverables.

# Design Process

## Steps in Defining Project Scope

- **Set Sustainability Benchmarks**
  - Example: LEED rating goals, carbon footprint limits, energy performance index.
- **Identify Risks and Constraints**
  - Include climate conditions, material availability, regulatory limitations, etc.
- **Review with Stakeholders**
  - Get consensus to avoid scope creep (uncontrolled expansion).

# Design Process

## Importance of Scope Definition

- **Clarifies responsibilities** and prevents duplication of work.
- **Avoids misunderstandings** among team members and clients.
- **Supports cost and time management.**
- **Integrates sustainability early** into design.
- **Serves as baseline** for progress measurement.

# Design Process

## Example: Sustainable Urban Road Design

- **Goal:** Reduce vehicle emissions and improve pedestrian safety.
- **Scope:**
  - Include: Road geometry design, material selection, pedestrian paths, drainage, solar street lighting.
  - Exclude: Toll collection system, public transport operations.
- **Deliverables:** Detailed design drawings, cost estimation, environmental assessment report.

# Design Process

## ASSIGNING THE DESIGN PROBLEM

- **Assigning the design problem** means officially defining and delegating the **task or challenge** that the design team must solve.
- It marks the **starting point of the design process**, where the team understands **what is to be designed, why, and for whom**.
- The problem statement gives the **context, constraints, and desired outcomes** of the design task.

# Design Process

## ASSIGNING THE DESIGN PROBLEM: Purpose

- To ensure all team members have a **common understanding** of the project.
- To define **boundaries** and **responsibilities**.
- To align the team's efforts toward **sustainable objectives**.

# Design Process

## Steps in Assigning a Design Problem

- **Problem Identification**

- Recognize the need for a design solution (e.g., inadequate drainage system, traffic congestion, excessive energy use in buildings).

- **Problem Definition**

- Clearly describe the nature of the problem.
- Example: *“Design a rainwater harvesting system for a residential complex to reduce dependency on municipal water supply.”*

- **Information Gathering**

- Collect background data — site conditions, environmental regulations, user requirements, budget, materials, etc.

# Design Process

## Steps in Assigning a Design Problem

- **Problem Breakdown**
  - Divide the main problem into smaller sub-problems (structural, environmental, social, etc.) to assign to specific sub-teams.
- **Team Assignment**
  - Allocate responsibilities to individuals or groups based on expertise (e.g., structural engineer → load analysis, environmental engineer → water reuse design).
- **Approval of Problem Statement**
  - Finalized and approved by the client or project authority before proceeding.

# Design Process

## Characteristics of a Well-Defined Design Problem

- **Clear:** Unambiguous in purpose and scope.
- **Feasible:** Solvable within available resources.
- **Measurable:** Can assess success using performance indicators.
- **Sustainable:** Addresses environmental and social impacts.
- **Open-ended:** Allows creativity and innovation in solutions.

# Design Process

## Example

- **Project:** Sustainable Bus Terminal Design
- **Problem Statement:** Design an energy-efficient, low-emission bus terminal with proper passenger flow, waste management, and solar energy utilization.
- **Sub-teams:**
  - Civil: Structure and pavement
  - Electrical: Solar power and lighting
  - Environmental: Wastewater and solid waste system
  - Planner: Passenger flow design

# Design Process

## GOAL OF THE DESIGN

- The **goal of the design** refers to the **intended purpose or objective** that the final solution must achieve.
- In **sustainable design**, the goal is not only to fulfill functional and aesthetic requirements but also to **minimize environmental impact** and **enhance long-term value**.

# Design Process

## Key Aspects of Design Goals

Aspect	Description
Functionality	The design must serve its intended purpose efficiently.
Sustainability	Reduce negative environmental effects, conserve resources, and promote social well-being.
Economy	Must be cost-effective during construction and operation.
Safety	Ensure structural and public safety under all conditions.
Aesthetics	Visually pleasing and contextually appropriate.
Durability	Long-lasting performance with minimal maintenance.

# Design Process

## Steps in Setting the Goal of a Design

- **Understand Client/Community Needs** – Identify what problem the design must solve.
- **Analyze Environmental Context** – Consider site, climate, and local ecosystem.
- **Set Performance Targets** – E.g., energy efficiency, carbon reduction, safety levels.
- **Include Sustainability Metrics** – Resource use, waste management, recyclability.
- **Document Goals** – Record and communicate them clearly to all team members.

# Design Process

## Example

### Design Goal for a Sustainable Building:

- Reduce annual energy consumption by 30%.
- Reuse 50% of construction waste.
- Achieve natural daylight for 75% of indoor area.
- Ensure accessibility for all users.



# Design Process

## Importance

- Provides **direction** to design activities.
- Acts as a **benchmark** for evaluating success.
- Aligns all stakeholders toward **common sustainable objectives**.
- Encourages **innovation** while maintaining practicality.

# Design Process

## DESIGN SCOPE

- **Design scope** defines the **extent and boundaries** of the design activity.
- It specifies **what the team will design, to what level of detail**, and **within what constraints** (time, cost, and performance).

# Design Process

## Objectives of Defining Scope

- To prevent **scope creep** (uncontrolled expansion of work).
- To set **clear deliverables** for the team.
- To ensure **sustainability aspects** are included in the project from the beginning.
- To provide a **basis for time and cost planning.**

# Design Process

## Components of a Design Scope Document

Component	Description
Project Overview	Brief about project purpose and need.
Design Boundaries	What parts of the system/building are covered.
Deliverables	Reports, drawings, models, simulations.
Sustainability Targets	Environmental goals (e.g., energy reduction, material reuse).
Constraints	Budget, regulations, timeline.
Assumptions	Key factors assumed true (e.g., material availability).
Exclusions	Elements outside team responsibility.

# Design Process

## Process of Defining Design Scope

- **Analyze the Problem Statement** – Identify design needs and user expectations.
- **Determine Project Extent** – Physical limits (site area, structure) and performance limits.
- **Consult Stakeholders** – Clients, engineers, government authorities, and end users.
- **List Deliverables** – Specify outputs and documentation expected.
- **Finalize and Approve Scope** – Official confirmation to begin detailed design.

# Design Process

## Example

- **Project:** Urban Drainage System for a Smart City Zone
- **Design Goal:** Prevent urban flooding and ensure water reuse.
- **Scope:**
  - **Include:** Drainage network design, rainwater storage tanks, wastewater reuse plan.
  - **Exclude:** Pumping station operation and maintenance.
  - **Deliverables:** Hydraulic design report, layout drawings, and cost estimate.
  - **Sustainability Focus:** Reduce stormwater discharge and promote infiltration.

# Design Process

## Importance of Design Scope

- **Ensures clarity** among all stakeholders.
- **Defines resource needs** (time, cost, manpower).
- **Helps track progress** and evaluate design success.
- **Integrates sustainability principles** early in project planning.
- **Avoids rework** and miscommunication later in design stages.

# Design Process

## Importance of Design Scope

- **Ensures clarity** among all stakeholders.
- **Defines resource needs** (time, cost, manpower).
- **Helps track progress** and evaluate design success.
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- **Avoids rework** and miscommunication later in design stages.

# VALUE STREAMS

- In any engineering design process, **value** is created by converting **inputs (resources, knowledge, effort)** into **outputs (structures, systems, or products)** that fulfill user needs.
- A **value stream** represents **all the steps and processes**—both **value-adding and non-value-adding**—that are required to bring a design from concept to completion.
- In **sustainable engineering**, defining value streams helps in **identifying waste, improving efficiency, and enhancing the life-cycle value** of a project.

# VALUE STREAMS

## Value Stream:

A value stream is the **sequence of activities or processes** that an engineering team performs to design, develop, and deliver a product or system that provides **value to the customer and society**.

- It includes **all actions (both direct and indirect)** needed to:
  - Transform raw materials into usable products.
  - Deliver services to clients.
  - Maintain sustainability and performance throughout the life cycle.

# VALUE STREAMS

In sustainable design, “value” is not only **economic** but also **environmental** and social.

Type of Value	Description	Example in Civil Engineering
Functional Value	Fulfills intended use effectively	A bridge safely carrying traffic load
Economic Value	Cost-effective construction and maintenance	Using locally available materials
Environmental Value	Reduces ecological impact	Low-carbon concrete or recycled aggregates
Social Value	Improves community well-being	Inclusive design with pedestrian pathways
Aesthetic Value	Enhances visual and cultural appeal	Architecturally sensitive design in urban areas

# VALUE STREAMS

## Purpose of Defining Value Streams

- **Identify Non-value-adding Activities:** Detect waste in design, planning, or construction.
- **Improve Efficiency:** Streamline workflows and communication.
- **Ensure Sustainability:** Focus on life-cycle performance rather than short-term output.
- **Enhance Collaboration:** Clarifies who contributes what value at each design stage.
- **Support Decision-Making:** Enables comparison between design alternatives.
- **Optimize Resources:** Reduces material, time, and energy wastage.

# VALUE STREAMS

## Components of a Value Stream in Engineering Design

Component	Description
Inputs	Raw materials, data, energy, manpower, capital.
Processes	Steps that transform inputs into outputs (e.g., design, analysis, modeling).
Outputs	Design drawings, prototypes, or constructed facilities.
Value-Adding Activities (VA)	Activities that directly enhance the product's performance or sustainability.
Non-Value-Adding Activities (NVA)	Redundant reviews, delays, rework, or over-design.
Stakeholders	Designers, clients, contractors, end-users.

# VALUE STREAMS

## Steps in Defining Value Streams

- **Identify the Product or Service**
  - What is being designed or produced? (e.g., wastewater treatment plant, smart road system).
- **Map the Current Process**
  - Document all steps involved from concept → design → approval → construction → maintenance.
- **Classify Activities**
  - Identify **Value-Adding (VA)** and **Non-Value-Adding (NVA)** steps.

# VALUE STREAMS

## Steps in Defining Value Streams

- **Measure Process Performance**
  - Time, cost, resource usage, environmental footprint.
- **Analyze Waste and Bottlenecks**
  - Waiting times, duplicate efforts, unnecessary materials, or long approval cycles.
- **Redesign for Lean and Sustainable Flow**
  - Remove waste and redesign processes for continuous value improvement.
- **Monitor and Continuously Improve**
  - Reassess the stream after design implementation for further optimization

# VALUE STREAMS

## Benefits of Defining Value Streams

- **Improved Process Transparency** – Every activity is visible and traceable.
- **Reduced Waste** – Helps identify unnecessary steps or over-design.
- **Higher Quality Design** – Focus on sustainable value creation.
- **Better Collaboration** – Cross-functional teams understand each other's roles.
- **Optimized Resources** – Material, energy, and time efficiency.
- **Supports Life-Cycle Thinking** – Encourages long-term performance over short-term cost.
- **Enhanced Client Satisfaction** – Delivering higher value with lower resource input.



# Sustainability Constraints in Design

Sustainability constraints are **limitations or boundaries** that ensure the design solution does not compromise environmental, social, or economic systems — both in the short and long term.

## **Purpose:**

- To make sure that engineering design.
- Meets present needs without compromising the ability of future generations to meet theirs.
- Balances **economic growth, social welfare, and environmental protection.**

# Sustainability Constraints in Design

## Example

Type	Description	Example
Environmental	Minimizing resource use, emissions, waste	Use of low-carbon concrete
Social	Promoting community well-being, safety, equality	Barrier-free access design
Economic	Ensuring life-cycle cost efficiency	Using durable, low-maintenance materials
Regulatory	Following environmental norms and standards	Adhering to EIA, MoEFCC, ISO 14001



# Sustainability Constraints in Design

## Guiding Principles for Sustainable Design

- **Holistic Thinking**

- Consider the entire system — materials, processes, environment, and lifecycle.
- Example: Analyzing a bridge not just for load capacity but also its carbon footprint, recyclability, and end-of-life reuse.

- **Resource Efficiency**

- Minimize use of energy, water, and materials.
- Implement *Reduce–Reuse–Recycle (3R)* concept.



# Sustainability Constraints in Design

## Guiding Principles for Sustainable Design

- **Life Cycle Thinking (LCA)**
  - Assess the environmental impact of a product or project from cradle to grave — raw material → construction → operation → disposal.
- **Pollution Prevention**
  - Design should avoid waste and emissions rather than control them later.
  - Example: Using renewable energy sources at site.
- **Equity and Social Responsibility**
  - Design should benefit society fairly — providing accessibility, safety, and inclusion.



# Sustainability Constraints in Design

## Guiding Principles for Sustainable Design

- **Economic Viability**

- Ensure design remains cost-effective through life-cycle costing (not just initial cost).

- **Resilience and Adaptability**

- Ability to perform under changing conditions such as climate, population, and technology.

- **Stakeholder Collaboration**

- Involve all affected groups (community, users, government, NGOs) from start to finish.

# Sustainability Constraints in Design

## The Triple Bottom Line (TBL): People, Planet, Profit/Prosperity

Dimension	Description	Example in Civil Engineering
People (Social)	Focus on human well-being, equity, safety, health, and community benefit.	Inclusive infrastructure, safe pedestrian pathways, equitable urban design.
Planet (Environmental)	Protect natural systems and resources; reduce pollution and emissions.	Use of fly ash in concrete, rainwater harvesting, green roofs.
Profit / Prosperity (Economic)	Ensure the project is economically viable and beneficial to the local economy.	Life-cycle cost analysis, use of local materials and labor.

# Sustainability Constraints in Design

## Required Domain Knowledge

Domain	Knowledge Required	Role in Sustainability
<b>Civil/Structural Engineering</b>	Materials, design codes, durability, maintenance	Optimize resource use and strength
<b>Environmental Engineering</b>	Water quality, waste management, EIA	Reduce ecological impact
<b>Architecture/Urban Planning</b>	Space utilization, aesthetics, energy efficiency	Integrate functionality and environment
<b>Economics/Management</b>	Cost-benefit analysis, financial sustainability	Evaluate project feasibility
<b>Social Sciences</b>	Community participation, behavioral patterns	Improve social acceptance and inclusion
<b>Information Technology (GIS, BIM)</b>	Smart modeling, data analysis	Improve efficiency and sustainability tracking



# Sustainability Constraints in Design

## Partner and Stakeholder Identification

Stakeholders are **individuals, groups, or organizations** who have an **interest, influence, or impact** on the project.

# Sustainability Constraints in Design

## Types of Stakeholders

Category	Examples	Role
<b>Internal Stakeholders</b>	Design team, project managers, engineers, contractors	Directly involved in planning and execution
<b>External Stakeholders</b>	Government bodies, local communities, NGOs, clients	Indirectly influence decisions and outcomes
<b>Knowledge Partners</b>	Academic institutions, consultants, research labs	Provide specialized technical input
<b>Regulatory Agencies</b>	Pollution Control Boards, Urban Development Authorities	Enforce sustainability and safety norms
<b>Financial Partners</b>	Banks, investors, funding agencies	Evaluate economic sustainability

# Design Synthesis

**Design synthesis** is the stage where all gathered information, constraints, goals, and value-stream insights are **combined to generate feasible, practical, and sustainable design solutions.**

It transforms problem understanding into **concepts, alternatives, and final design options.**

## Key tasks:

- Integrating interdisciplinary inputs
- Balancing sustainability (People–Planet–Profit)
- Evaluating performance and risks
- Producing optimized solutions

# Design Synthesis

## Integral Synthesis

**Integral (Integrated) synthesis** refers to combining **technical, social, environmental, and economic inputs** into a single unified design approach.

### Features

- **Cross-disciplinary integration**

Structural, environmental, architectural, economic, and social factors are merged.

- **Holistic sustainability alignment**

Ensures design meets sustainability constraints and guiding principles.

- **System-level thinking**

Every subsystem is considered part of a whole

(materials → construction → operation → disposal).

# Design Synthesis

## Integral Synthesis: Features

- **Iterative refinement**

Solutions are repeatedly improved using feedback from stakeholders and domain experts.

### **Example:** In designing a water treatment plant:

- Civil → structures
- Environmental → treatment process
- Electrical → energy efficiency
- Cost engineer → life-cycle cost
- Community input → odour/noise limitations
- All these are integrated into one cohesive design.

# Design Synthesis

## Generation of Solutions

- This step develops **multiple conceptual alternatives** that satisfy the design problem, goals, scope, and sustainability constraints.

## Process

- **Brainstorming**

Generate as many ideas as possible without judgment.

- **Morphological analysis**

Break the problem into components and explore permutations (e.g., material → layout → technology → energy options).

- **TRIZ (Theory of Inventive Problem Solving)**

Resolve contradictions (e.g., high strength vs. low carbon footprint).

# Design Synthesis

## Generation of Solutions: Process

- **Benchmarking**

Study best practices from existing sustainable projects.

- **Concept sketches & models**

Initial drawings, 3D models, simulation setups.

- **Screening and shortlisting:** Evaluate ideas based on:

- Feasibility
- Sustainability performance
- Cost and risk
- Client/user needs
- Regulatory compliance

# Design Synthesis

## Risk Assessment and Mitigation by Research & Development

- Risk assessment identifies **potential failures, uncertainties, and negative impacts** during design, construction, and life-cycle stages.
- Research & development (R&D) helps **mitigate risks** by generating knowledge, new technologies, and improved methods.

# Design Synthesis

## Types of Risks in Engineering Design

Risk Type	Examples
Technical risks	Structural failure, material inadequacy
Environmental risks	Pollution, resource depletion, flooding
Economic risks	Budget overruns, high maintenance cost
Social risks	Public opposition, safety hazards
Regulatory risks	Non-compliance with codes and EIA norms
Operational risks	Poor durability, difficult maintenance

# Design Synthesis

## Steps in Risk Assessment

- **Risk Identification**
  - Site risks (soil, weather)
  - Construction risks
  - Sustainability risks (carbon footprint, waste, emissions)
- **Risk Analysis**
  - Probability vs. impact
  - Tools: HAZOP, Fault Tree Analysis

# Design Synthesis

## Steps in Risk Assessment

- **Risk Evaluation**
  - Rank based on severity
  - Determine acceptable/unacceptable risks
- **Risk Mitigation Planning**
  - Reduce
  - Avoid
  - Transfer
  - Accept (if low impact)
- **Monitoring**
  - Track risks through project lifecycle
  - Update design based on new findings

# Design Synthesis

## Role of Research and Development (R&D) in Mitigation

- **Development of new materials**
  - High-performance concrete (HPC)
  - Recycled aggregates
  - Low-carbon cement
- **Advanced technologies**
  - BIM for clash detection
  - GIS-based risk mapping
  - AI-based simulation and optimization

# Design Synthesis

## Role of Research and Development (R&D) in Mitigation

- **Environmental studies**
  - Climate-resilient design
  - Life-cycle assessment (LCA)
- **Testing and Prototyping**
  - Lab testing of materials
  - Pilot projects
  - Simulation models
  - Wind tunnel tests (for structures)

# Design Synthesis

## Role of Research and Development (R&D) in Mitigation

- **Adapting global best practices**
  - Green building standards (LEED, GRIHA)
  - Smart infrastructure technologies
- **Feedback from operation and maintenance**
  - Field data → redesign → improved solutions