NAVIGATING DIGITAL TWIN IMPLEMENTATION IN THE CIRCULAR BUILT ENVIRONMENT.

Identifying technological inhibitors to implementation of digital twins from the perspective of early and potential adopters

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NAVIGATING DIGITAL TWINS IMPLEMENTATION IN THE CIRCULAR BUILT ENVIRONMENT.

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Introduction

- **Global Warming is ravaging the Planet**
- **40 %** of materials used.
- A **third of emissions** generated**.**
- Only 10 % of Dutch GNP generates 45% of waste
- The construction industry (CI) has one of the **most linear value chains.**
- **Only 50%** is recycled
- **Downcycling** is a significant issue.

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Introduction

- **Circular economy** concepts in the built environment offers developers and building customers a substantial potential to decrease lost value sources, boost the financial return from built environment assets, and facilitate the achievement of sustainability targets
- **Digital twins** can be a key element in the transition from linear construction to circular construction, through being part of a wider framework of technologies. Some research has been conducted into such possible frameworks.

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Problem Statement

There is within scientific literature a lack of research regarding the possible barriers and challenges for circular construction in the Dutch built environment from the perspective of the various stakeholders that will employ these technologies. Therefore, this research will focus on the current adoption of Digital Twin technology in the Dutch built environment by current adopters and those who are active in the realization of circular real estate but have not yet implemented the technology. In order to identify challenges experienced with the adoption of the technology, issues with current forms of adoption and possible barriers or challenges observed by those who are yet to adopt the technology.

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Hypothesis

The circularity techniques employed by a corporation are determined by its special needs, which subsequently influence the desire or perceived necessity for digital twins with certain characteristics. This in turn dictates the barrier or challenges that are related to the implementation of Digital Twin technologies for circularity purposes.

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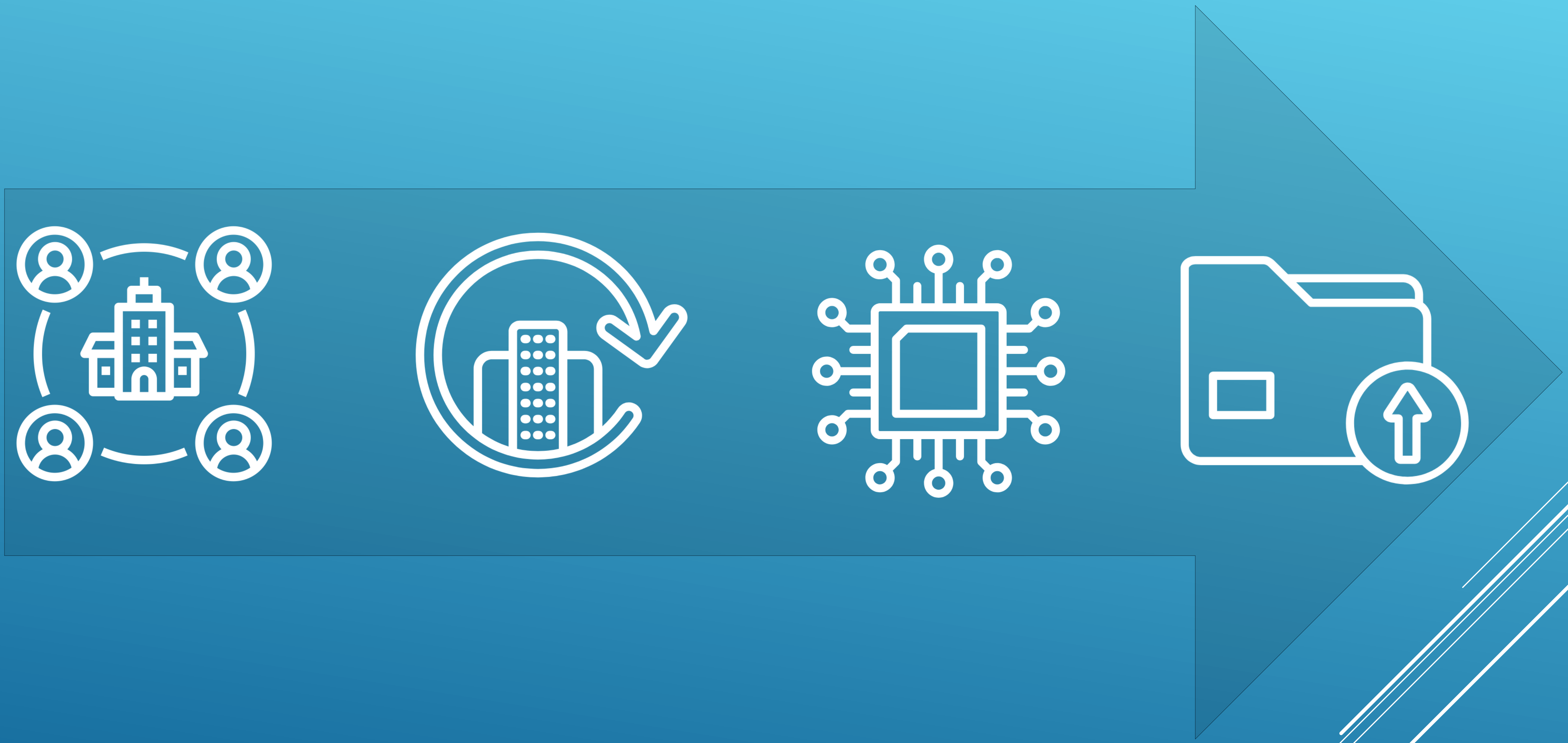
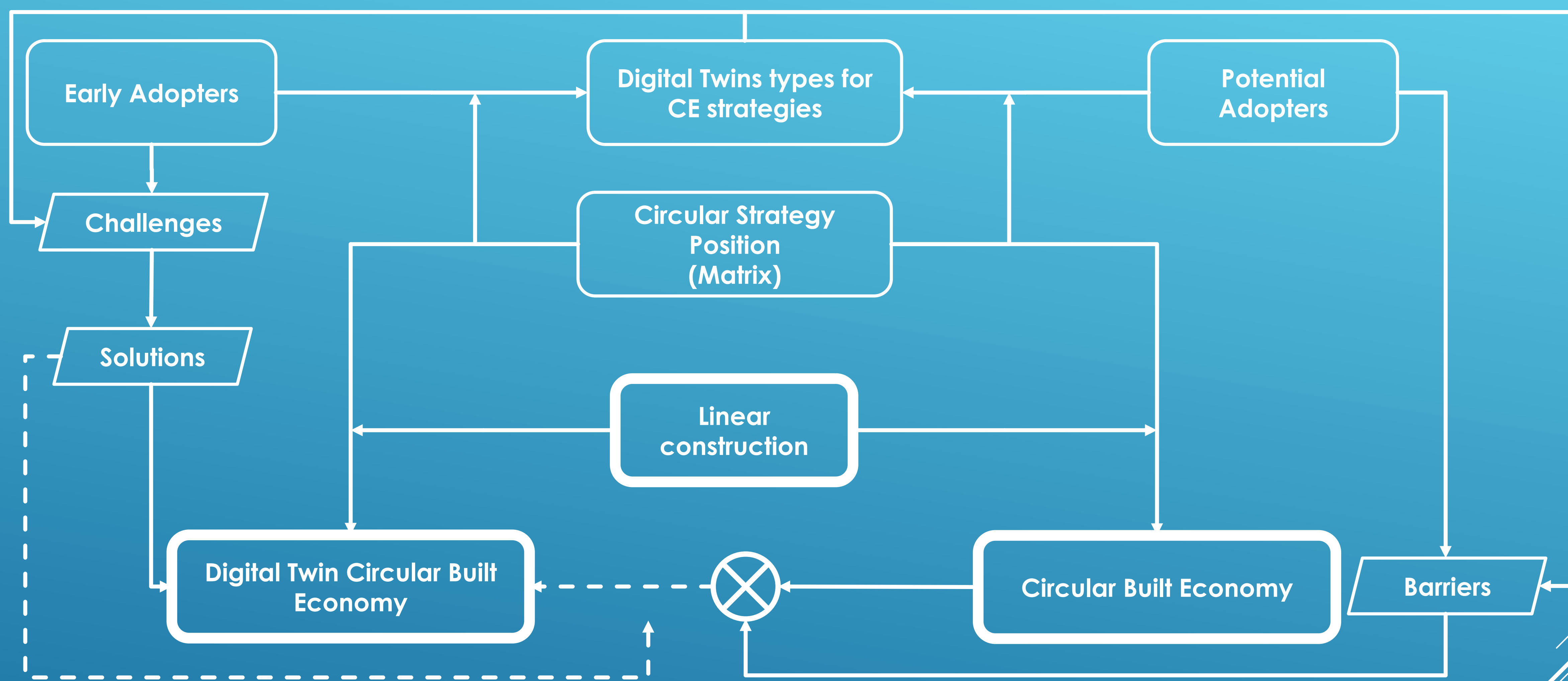
Hypothesis



Conceptual Framework



Barriers blocking use of digital twins

Possible application of solutions to allow for Digital Twin implementation in the CBE

Research Question

Main RQ: “What are the observed and anticipated barriers and challenges for early and potential adopters of Digital Twins technologies in the Dutch circular-built environment?”

Sub question 1. How is circular construction implemented in the Netherlands?

- What is the Built environment?
- How is the construction industry structured?
- What is circularity in the built environment and how can it be achieved?
- What are the barriers to the creation of a circular construction industry?

Sub question 2. What are Digital Twins for the Circular Built environment?

- What are Digital Twins and what are their capabilities?
- How can they enable circular strategies?
- How can they been used to enable circular strategies in the Dutch construction sector?

Sub question 3. What are the observed and perceived barriers and challenges for the adoption of Digital Twin in circular construction?

- Which barriers and challenges did the early adopters of Digital Twin technologies experience?
- What barriers and challenges do other potential users perceive in the adoption of Digital Twin technologies?

Sub question 4. What are the employed and possible solutions for the experienced challenges and how do these overlap with barriers?

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Research Question

Main RQ: What are the observed and anticipated barriers and challenges for early and potential adopters of Digital Twins technologies in the Dutch circular-built environment?

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Sub-Question

Sub question 1. How is circular construction implemented in the Netherlands?

a. What is the Built environment?
b. How is the construction industry structured?
c. What is circularity in the built environment and how can it be achieved?
d. What are the barriers to the creation of a circular construction industry?

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Sub-Question

Sub question 2. What are Digital Twins for the Circular Built environment?

a. What are Digital Twins and what are their capabilities?
b. How can they enable circular strategies?

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Sub-Question

Sub question 3. What are the observed and perceived barriers and challenges for the adoption of Digital Twin in circular construction?

a. Which barriers and challenges did the early adopters of Digital Twin technologies experience?
b. What barriers and challenges do other potential users perceive in the adoption of Digital Twin technologies?

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Sub-Question

Sub question 4. What are the employed and possible solutions for the experienced challenges and how do these overlap with barriers?

Research Methodology

Methodologies used:

- *Literature Research*
- *Case studies/Interview*
- *Interviewee Coding and Analysis*

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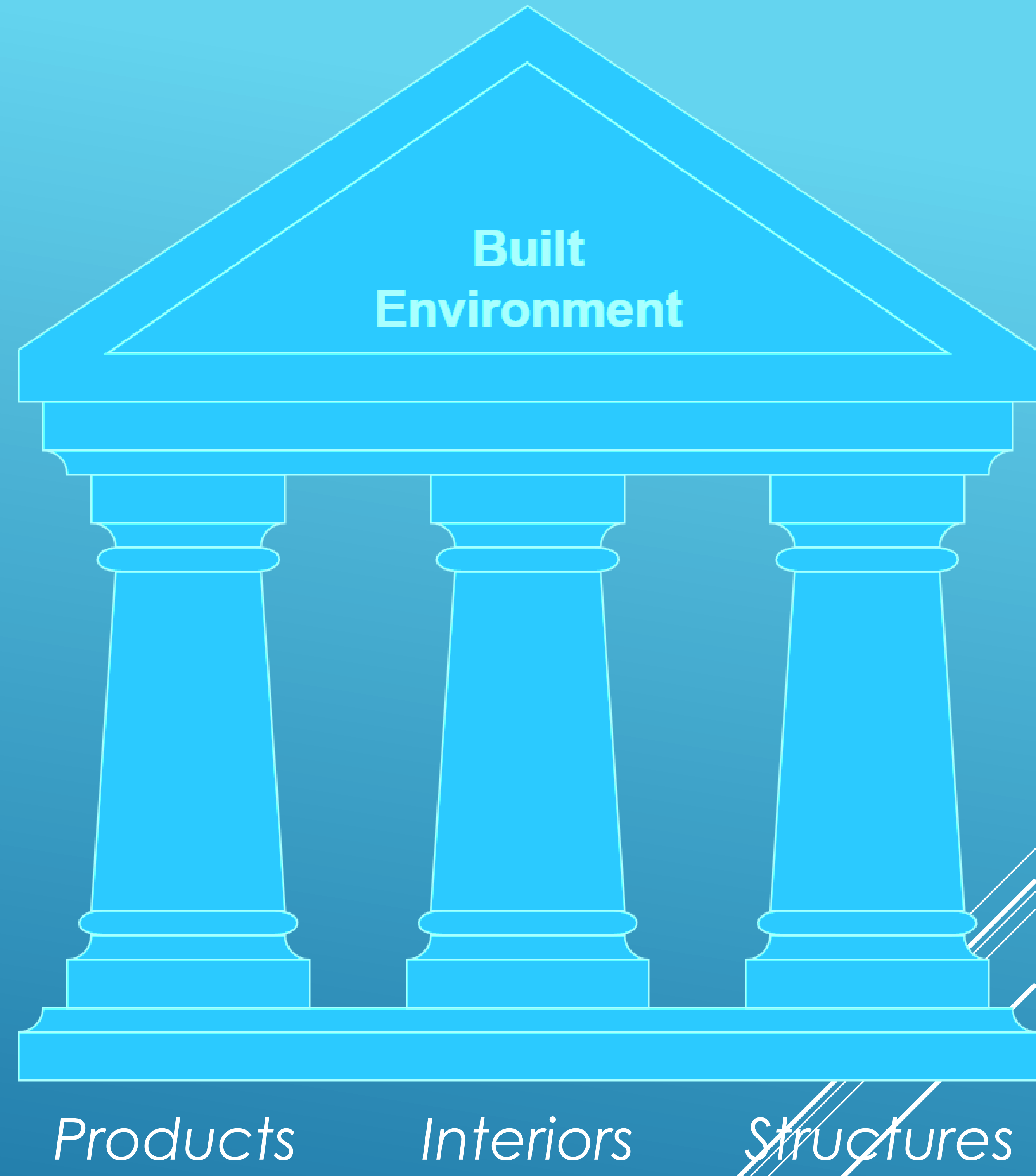
The Built Environment

*The built environment consists of **Products, Interiors** and **Structures**, grouped together with the purpose of facilitating human activity.*



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The Built Environment

Change Initiation	- Urban Planners - Allied Professionals - Engineers
Strategic Planning	- Urban Planners - Allied Professionals - Urban Designers - Engineers - Landscape Engineers - Construction Managers -Owners/Investors
Project Initiation/ Consideration	- Urban Planners - Property Advisors - Property Developers -Owners/Investors - Allied Professionals - Architects - Urban Designers - Landscape Engineers
Design	- Architects - Urban Designers - Landscape Engineers - Urban Planners - Property Advisors - Property Developers - Allied Professionals
Costing and Approval	- Property Developers - Engineers - Construction Managers - Allied Professionals - Property Advisors - Urban Planners - Architects - Urban Designers
Construction	- Construction Managers - Landscape Engineers - Property Developers - Property Managers - Allied Professionals -Owners/Investors
Use and Ongoing Management	-Owners/Investors - Urban Planners - Urban Designers - Landscape Engineers - Allied Professionals - Property Managers
Renewal, Recovery, Decommission	- Urban Planners - Property Managers - Property Developers - Property Advisors - Allied Professionals - Engineers

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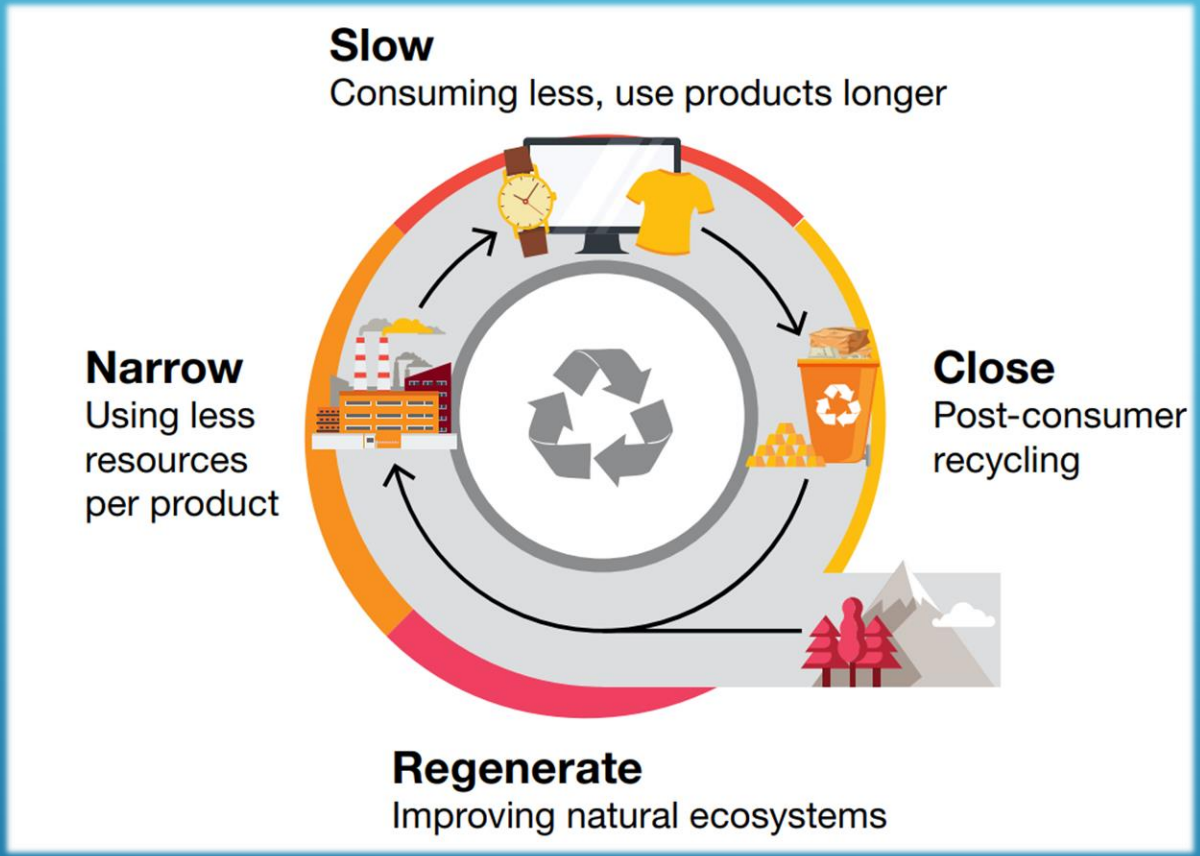
CIRCULARITY

Circularity Definition

Circularity in the built environment can be defined as various ***METHODS OR FRAMEWORKS, that prioritize the reduction, reuse, and recycling of materials, resources, and waste.***

CIRCULARITY



(Bocken et al, 2021)

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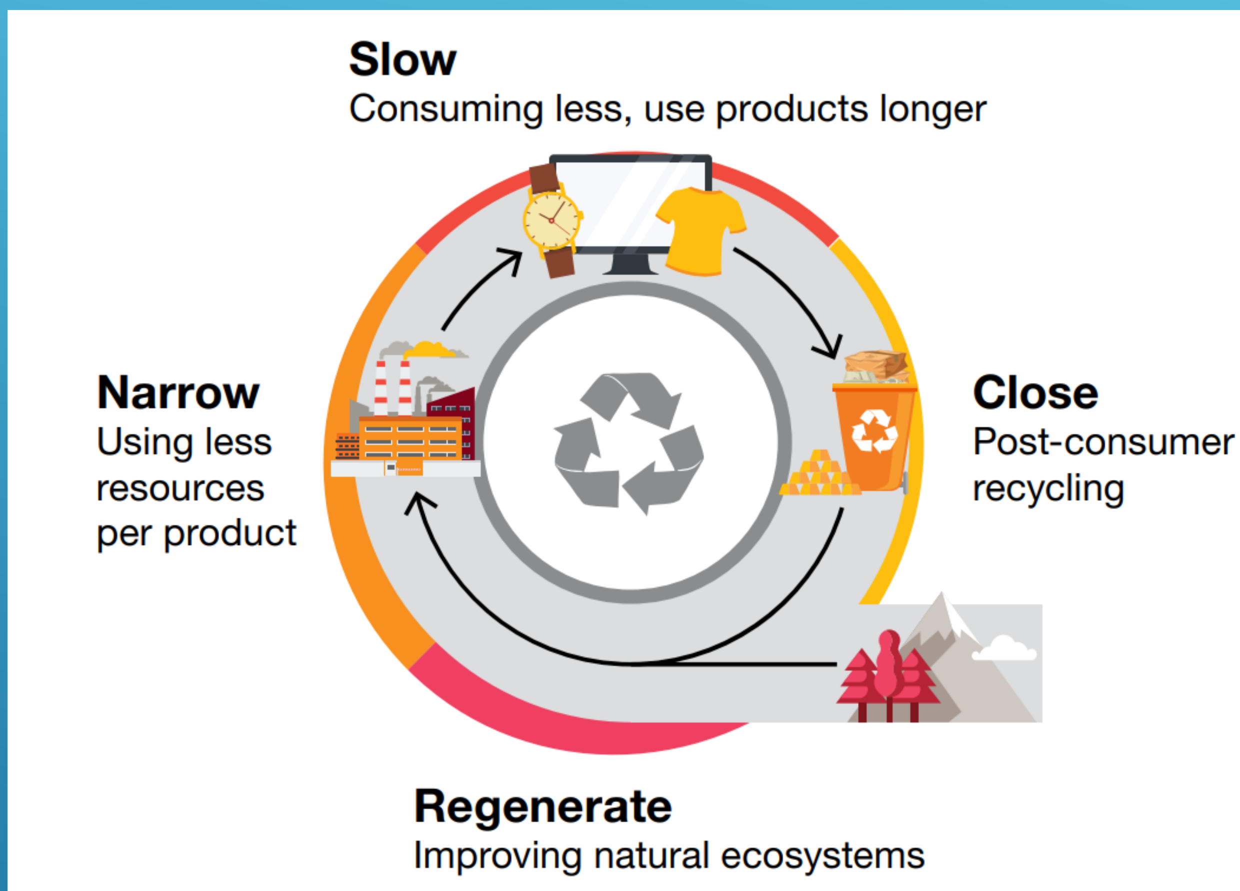
Circularity Strategies

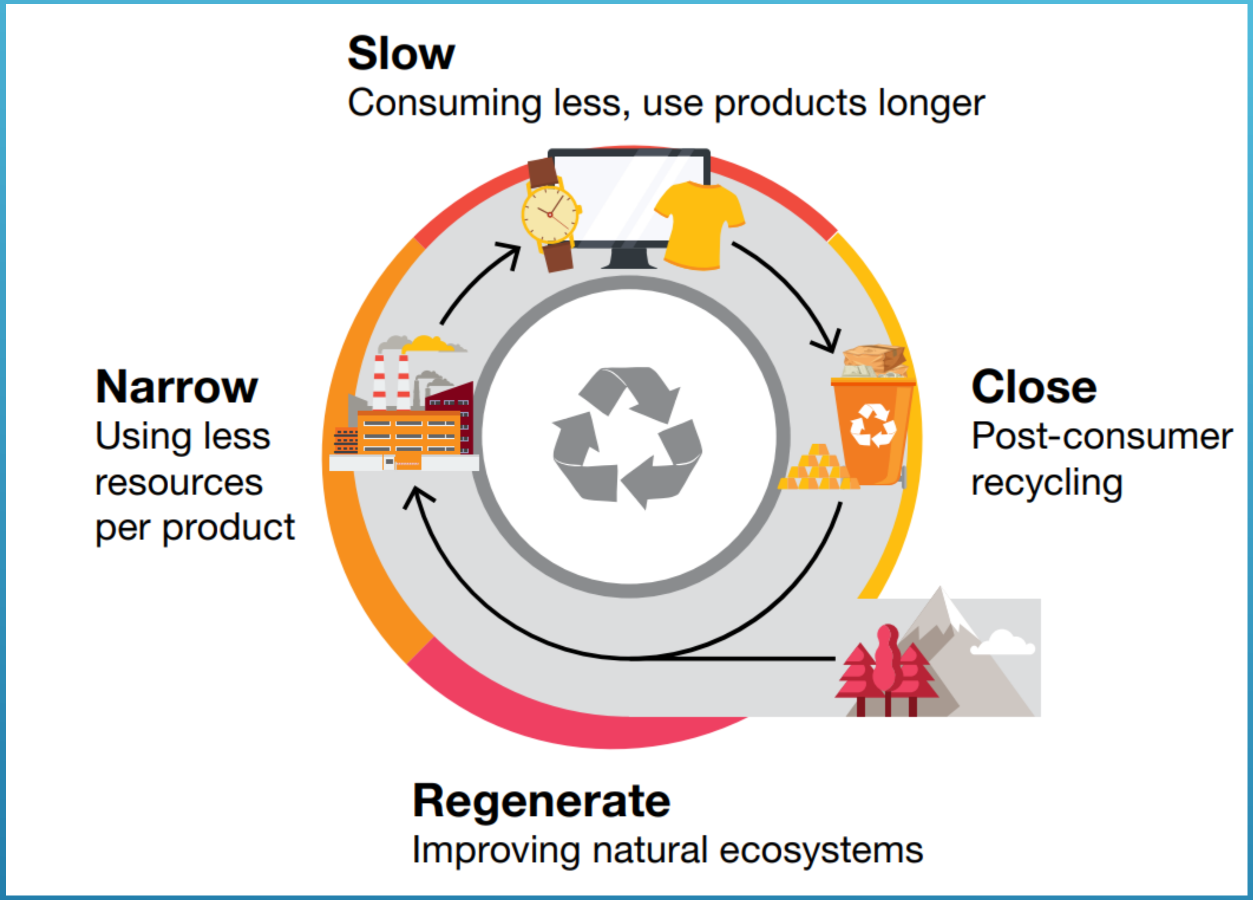


(Bocken et al, 2021)

Slow:

- Extending product life
- Design for physical durability
- Offer products as services
- From Disposable to reusable

Circularity Strategies



(Bocken et al, 2021)

Close:

- Reintroduce end of life components back into the cycle
- Design for recycling
- Incentivice recycling
- Organise recycling eco-systems

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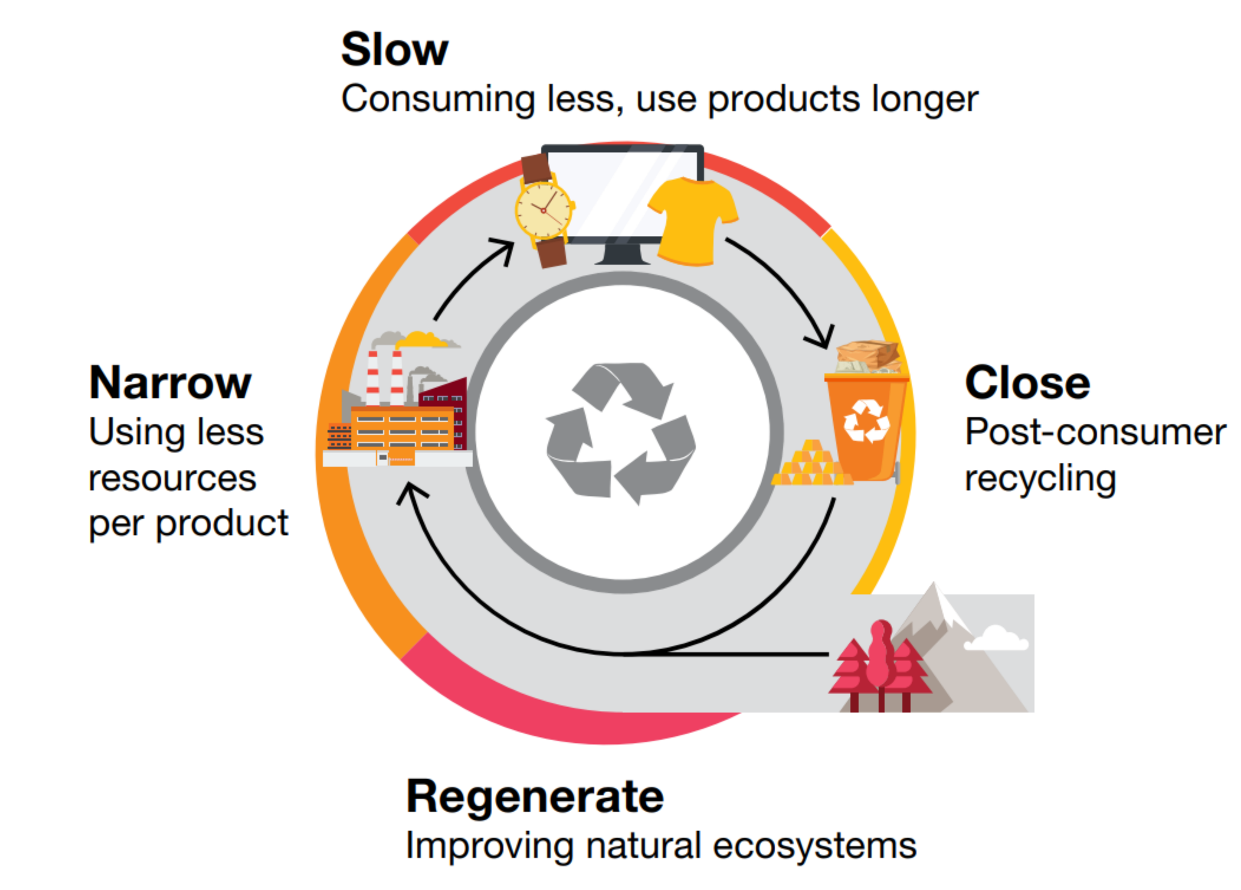
Circularity Strategies



(Bocken et al, 2021)

Regenerate:

- Reintroduce end of life components back into the cycle and improve environment
- Sustainable sourcing and component cycles
- Sustain ecosystems
- Reclaim lost nutrients and health of urban ecosystems

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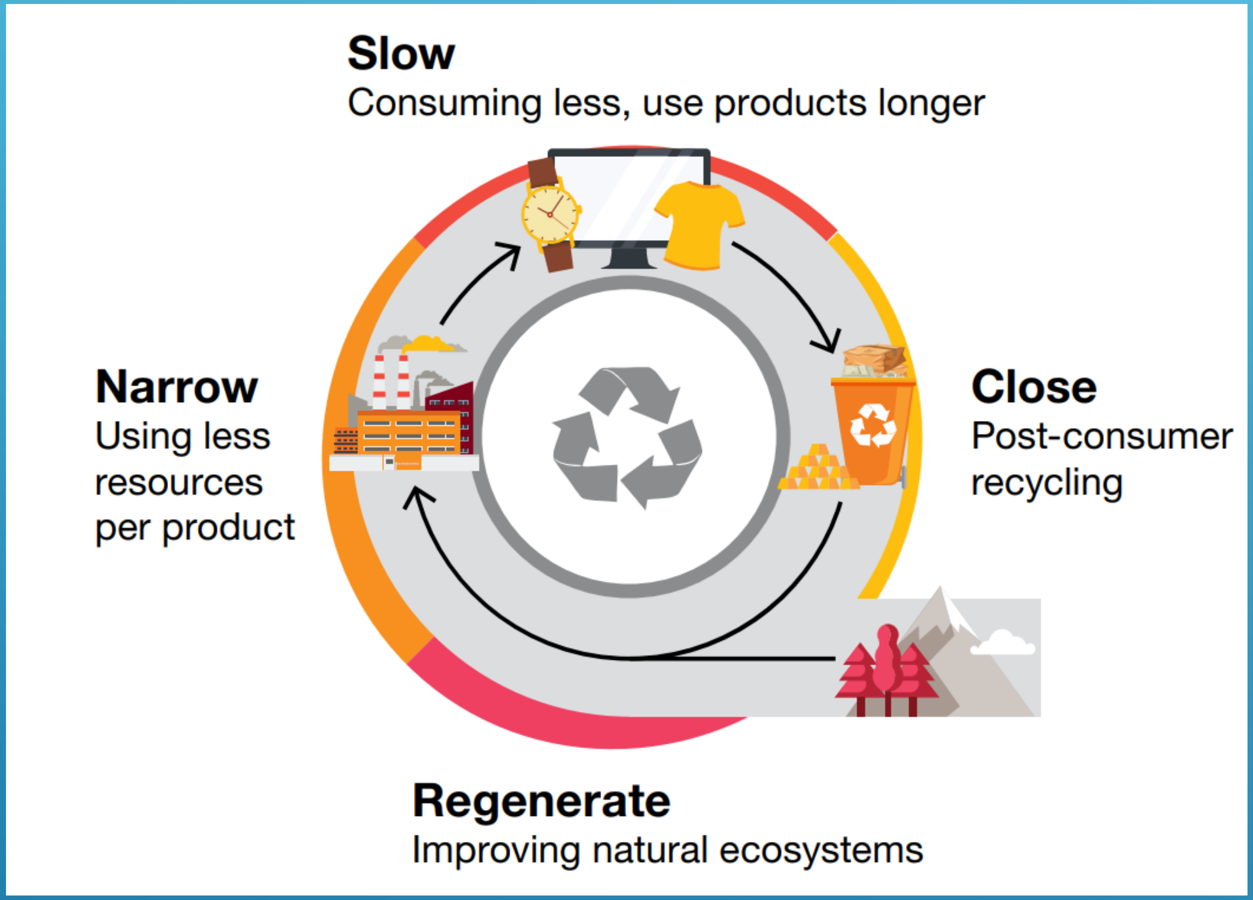
Circularity Strategies



(Bocken et al, 2021)

Narrow:

- Creating a BE that uses less
- Upgrades that enhance efficiency
- Sustain ecosystems
- Fewer components
- Designing with low impact inputs

Circularity Strategies

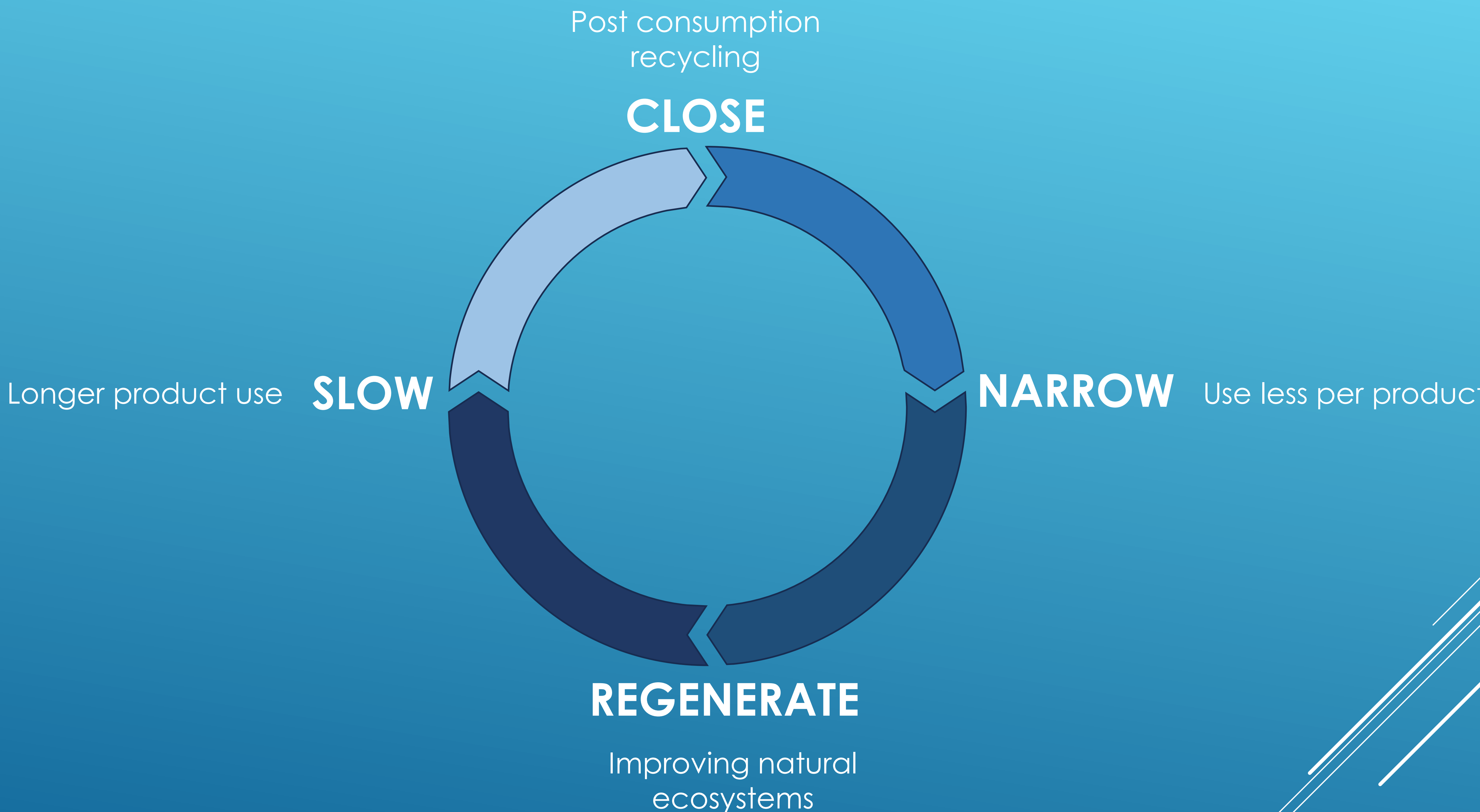


Figure: Defining circular resource-loop strategies (ADAPTED FROM Bocken, et al 2021)

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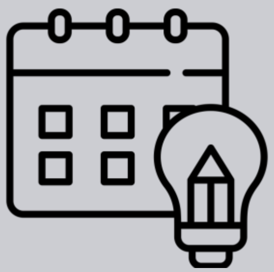
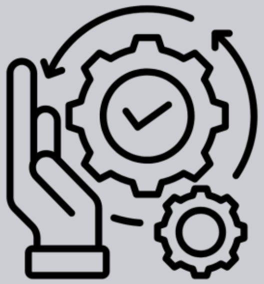
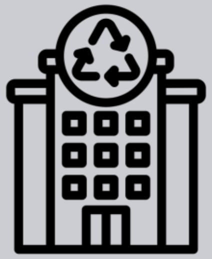
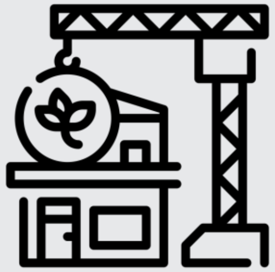
Circularity Matrix

	Pre Build	Construction	Use	End of Life
Slow				
Narrow				
Close				
Regenerate				

Circularity Matrix

	Pre Build	Construction	Use	End of Life
Slow	• Design for Durability & Longevity • Design for Maintenance & Repair • Standardization, Service Models & Warranties	• Encourage Efficiency • Products as a service	• Enable user repair & maintenance. • Provide repair & maintenance. • Upgrade And adaptability services	• Reuse, Repurpose & Remanufacture Products and components • Turn disposables into reusable services

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Circularity Matrix

	Pre Build	Construction	Use	End of Life
Narrow	• Design sustainable & lightweight products • Design multiple product functions • Enable and incentivise Resource Efficiency	• Organize light-weight urban transport. • Localize supply where appropriate	• Maximize capacity use of products	• Eliminate disposal wate

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Circularity Matrix

	Pre Build	Construction	Use	End of Life
Close	• Design with and for recycling • One material components • Design for easy disassembly	• Build with local waste to product loops • Take part with industrial symbiosis		• Enable & facilitate resource reuse and recycling. • Local resource loops and symbiosis

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Circularity Matrix

	Pre Build	Construction	Use	End of Life
Regenerate	• Sustainable Material Design • Design with renewable energy integration • Setup projects with sustaining critical ecosystems	• Produce, process and transport using renewable energies. • Build with products that use renewable energies. • Ecosystem regeneration and management	• Manage and sustain critical ecosystem services	• Contribute to regenerating polluted ecosystems • Manage and sustain critical ecosystem services

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Circularity Barriers

Regulatory & Political

Financial

Knowledge

Market

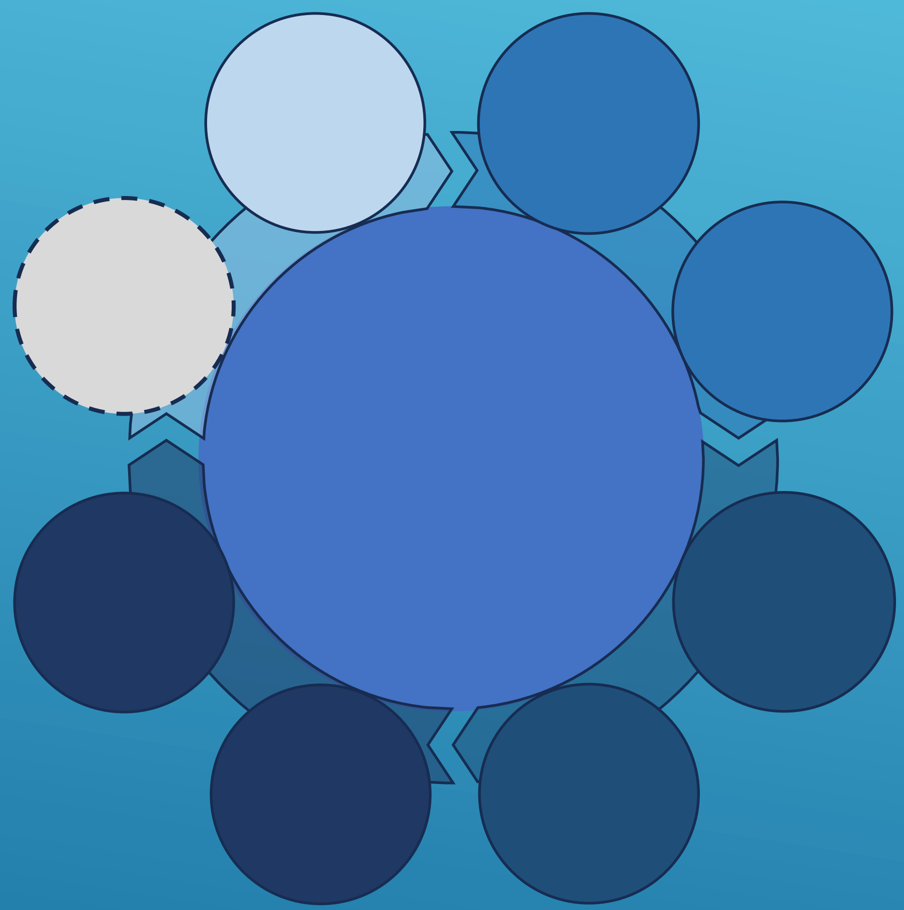
Supply Chain

Institutional

Technology

Environmental

Management



DIGITAL TWINS

Digital Twin Definition

A digital twin is a virtual representation of a physical asset, reflecting the real-world entity it models*. A key characteristic of a digital twin is its connection to the physical part, allowing it to* ***adapt and reflect changes over time****. Importantly, digital twins are not limited to the* ***software*** *component alone; they also encompass the* ***physical assets*** *they represent. In the AECO sector, the physical component includes built assets, while the digital component typically consists of* ***a model containing*** *linked information relevant to the physical asset and for the purpouses of this thesis the* ***network of technologies****.*

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Digital Twin Definition

Physical asset

Network of technologies

Model

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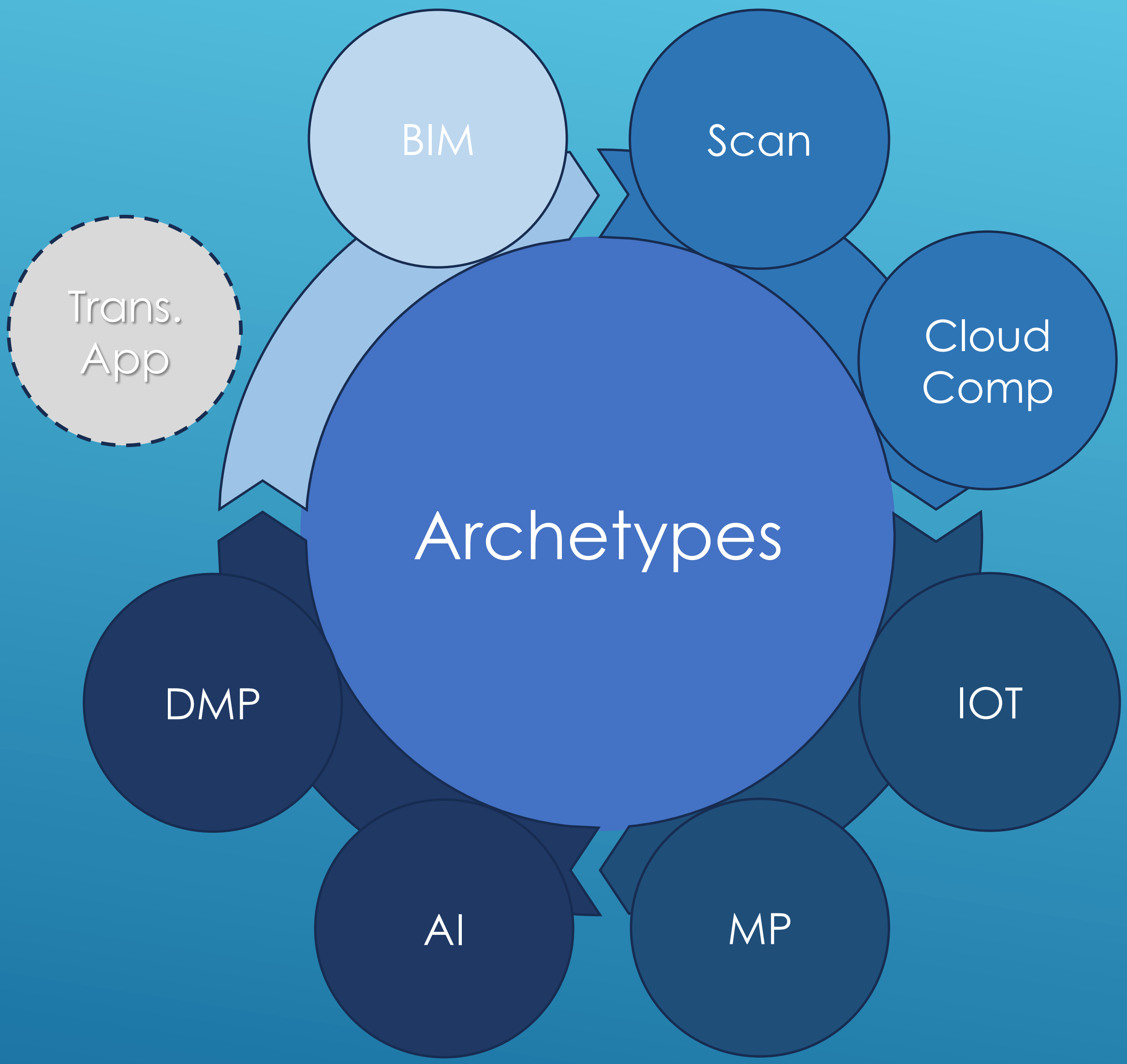
Digital Twins



BIM

Building information Model: Building Information Modelling (BIM) is a digital representation of the physical and functional characteristics. It represents the HMI.

Scan & sensors

Scanning & Sensors: Capturing the physical attributes and geometry of an object or environment using specialised equipment and techniques.

Cloud Comp

Cloud computing: Cloud computing refers to the delivery of computing services, including storage, processing power, and software applications, through the internet.

IOT

Internet of things: Method of connectivity between models and sensors to create a dynamic feedback loop and accesibility

AI

Artificial Intelligence: Predictive analysis based on algorithms trained on data sets

DMP

Digital Material Platforms: Multi-sided network, matching different groups of users to exchange goods and services

MP

Material Passports: Comphrensive data sets containing the physical properties of materials and components

Trans. App

Translation applications: Tools that can translate incoming and outgoing data into standards and information typologies usable by other platforms and twins

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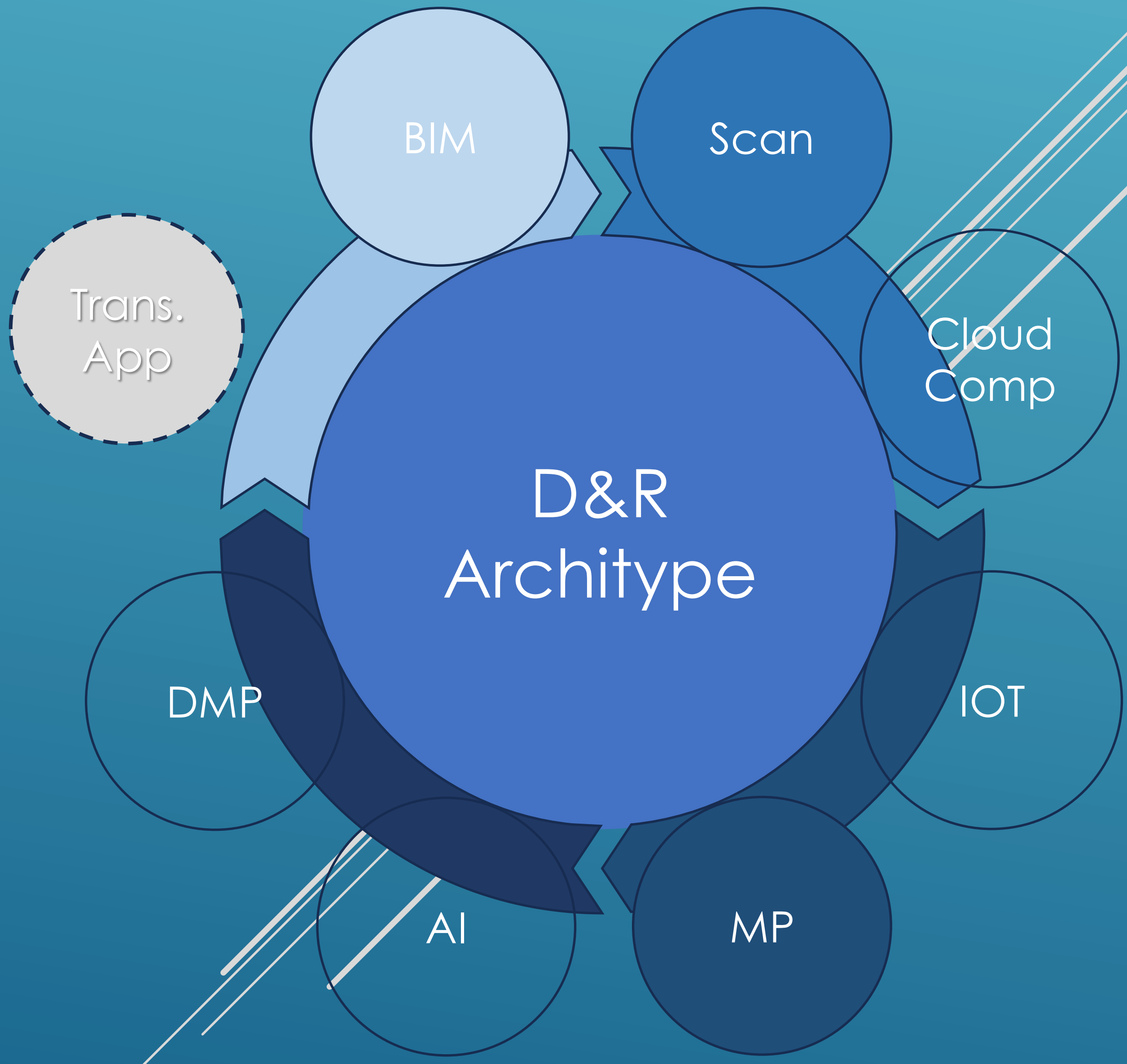
DESIGN AND DATA STORAGE



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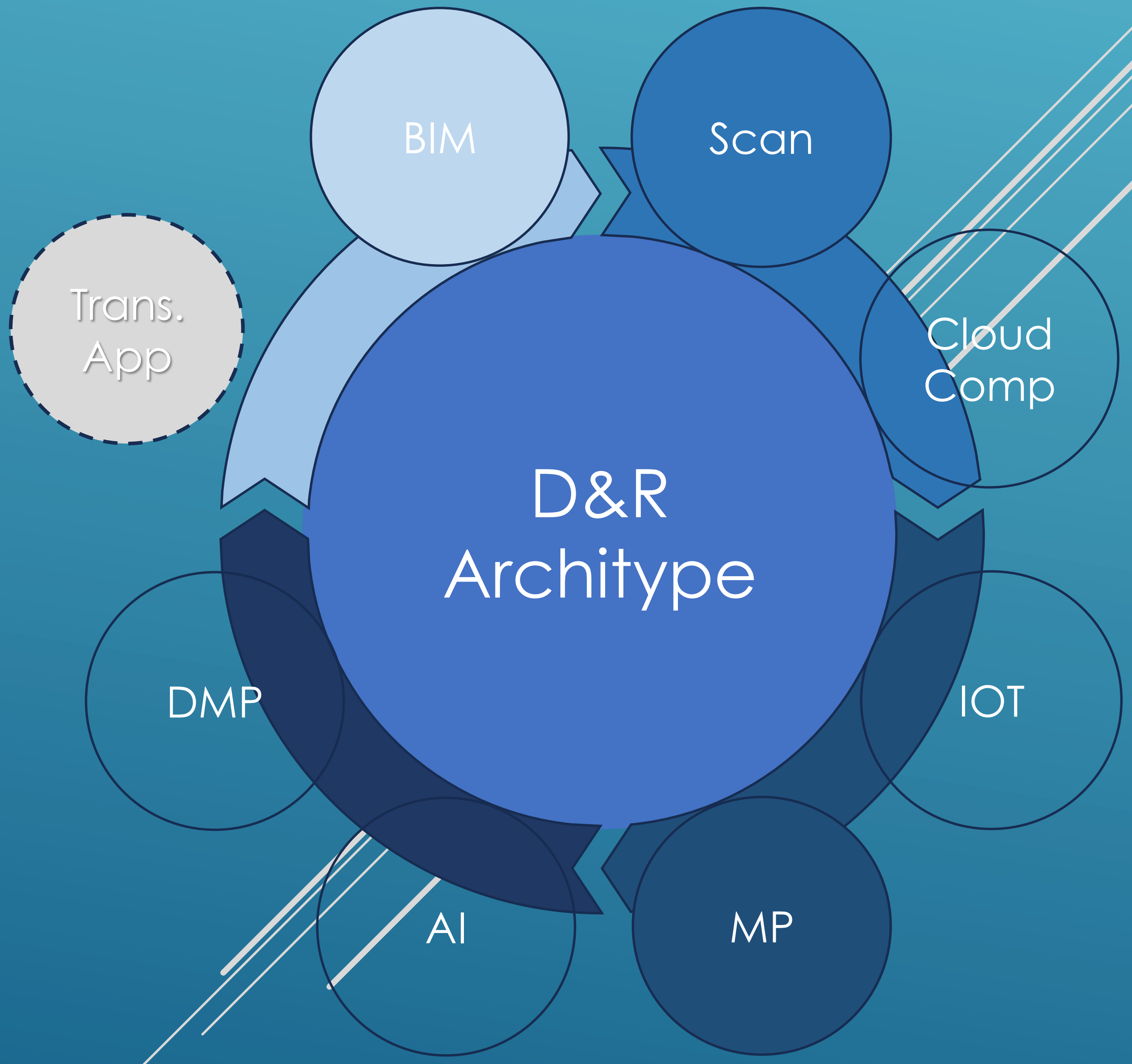
AT 1: Design & Repository Twin

This first digital twin is based on acting as a tool for storing data gathered from a building and as away for actors to interact with digital representations of buildings for example for design purposes.

- **BIM**
- **3D scanning**
- **Material Passports**



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This twin is used primarily for design and planning purposes, helping the building's stakeholders visualize and understand the structure, coordinate changes, and ensure the efficient use of materials and resources throughout the building's life cycle.

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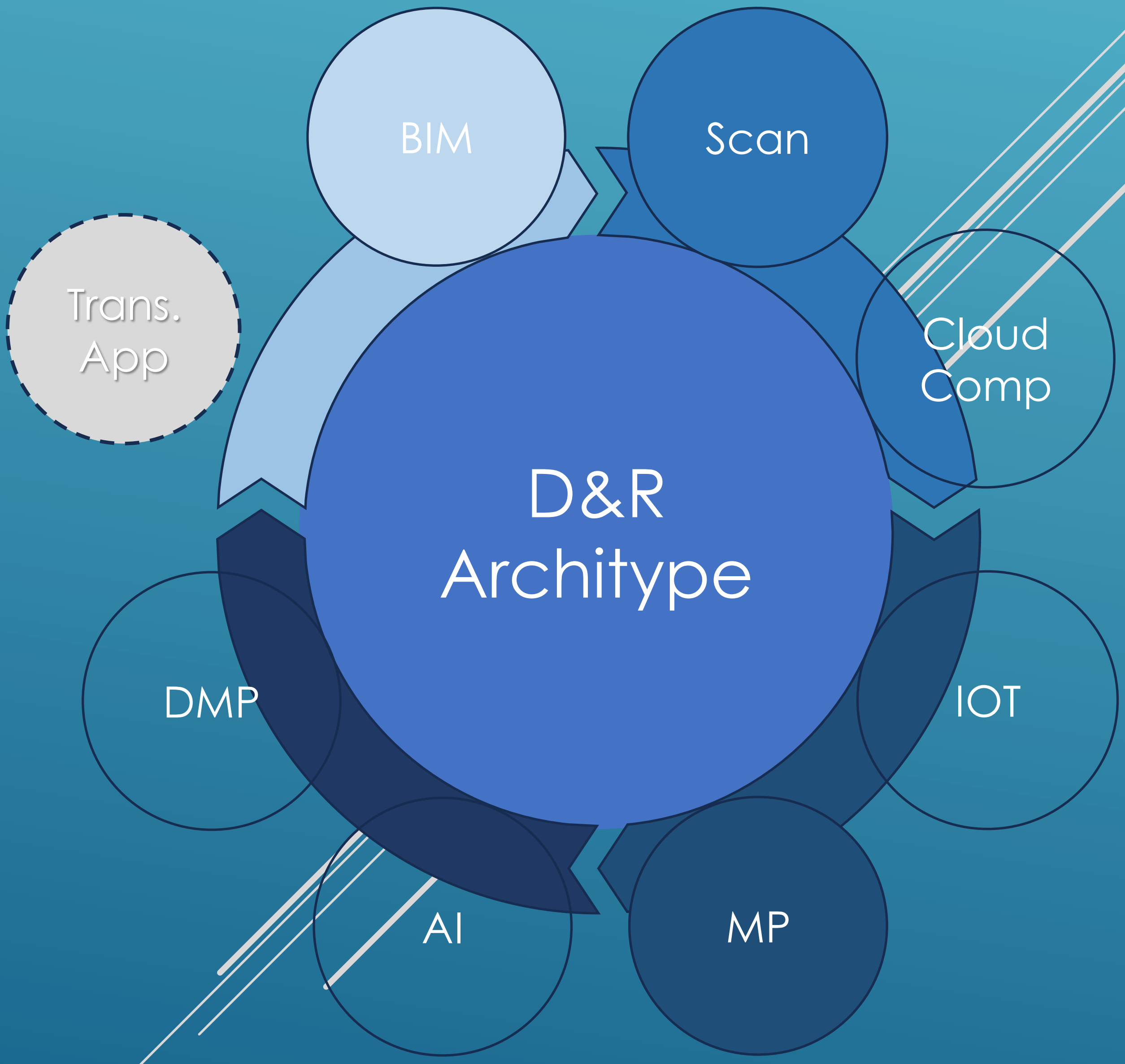
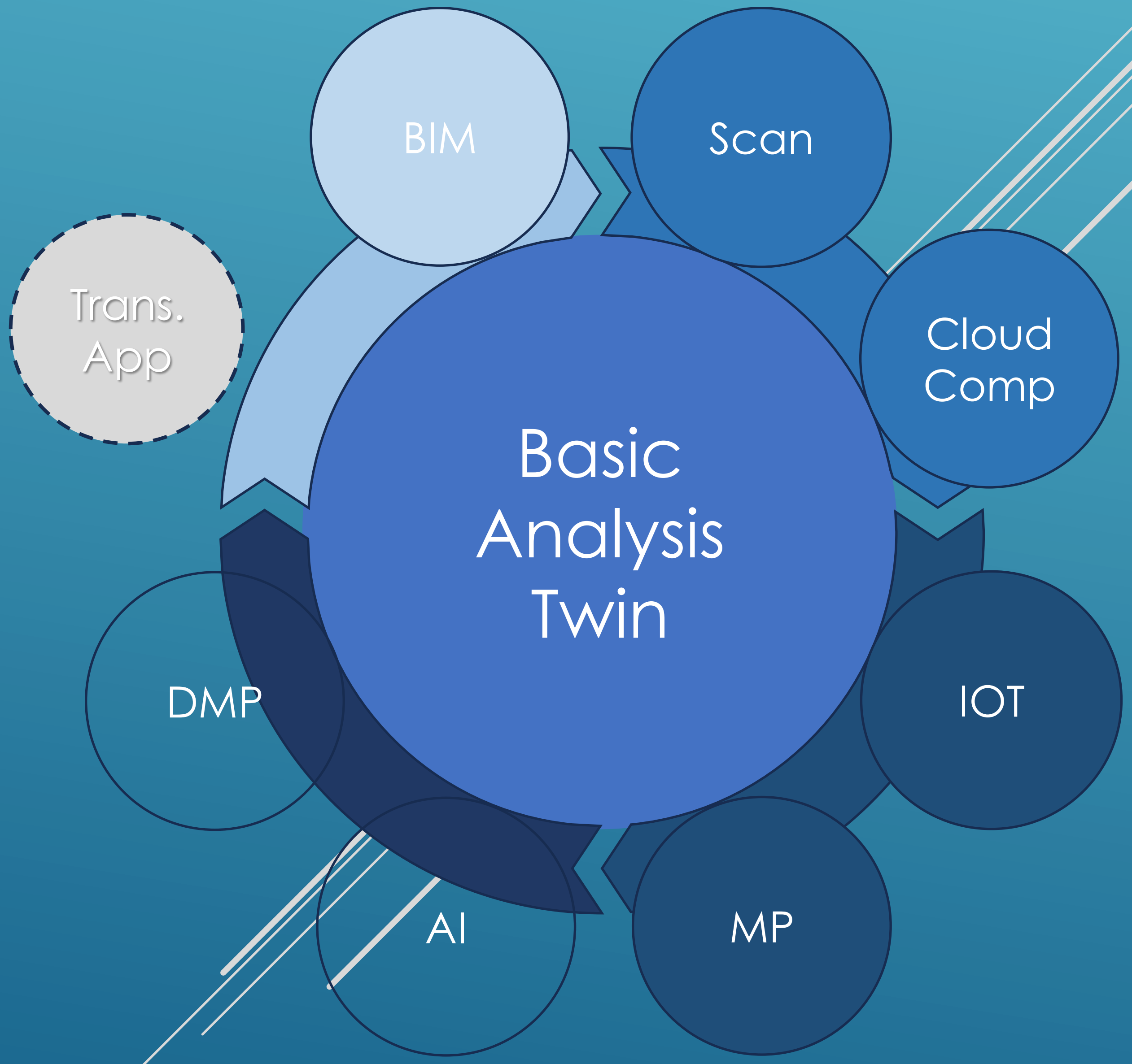


ANALYSIS

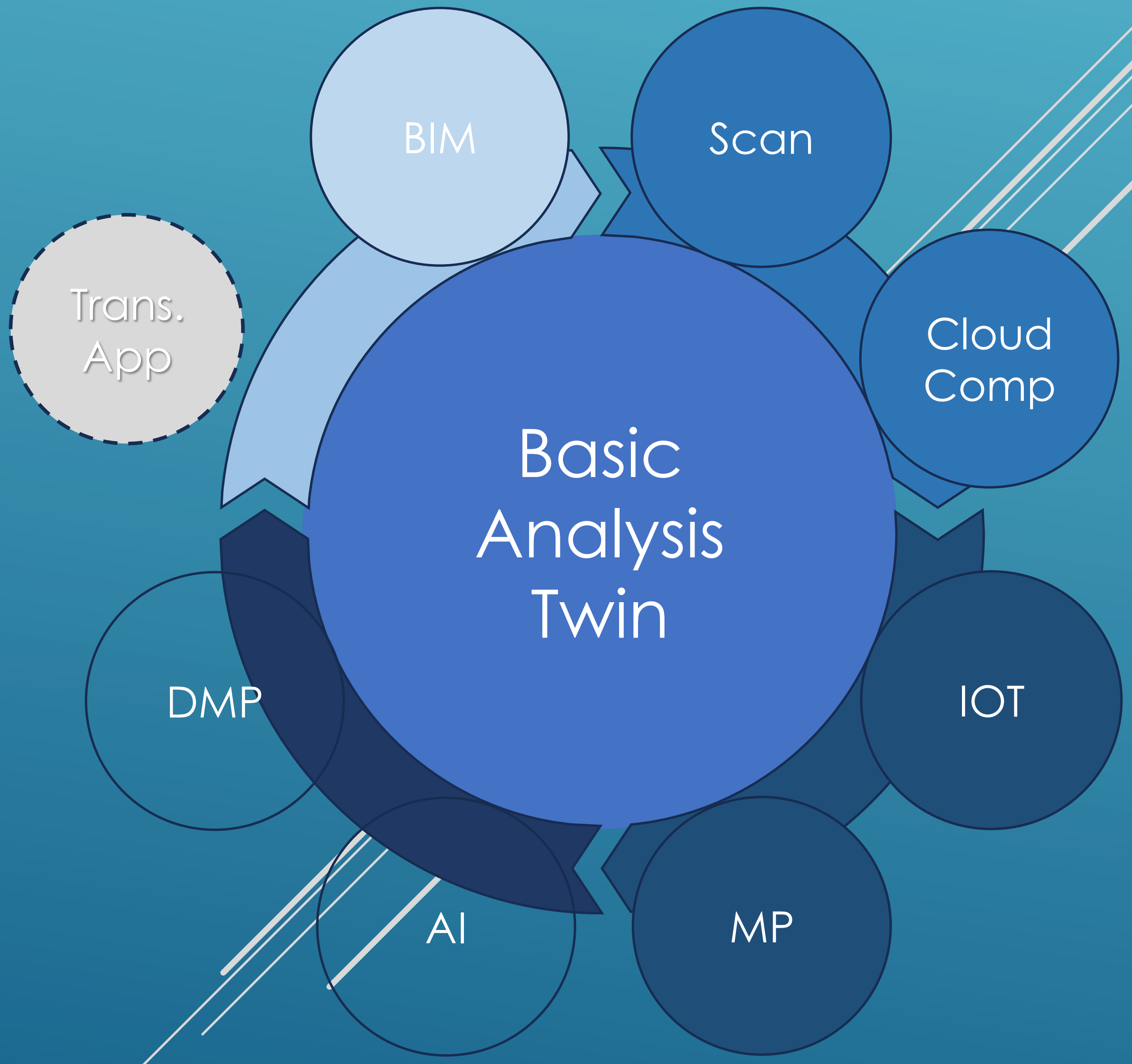


Trans. App
BIM
Scan
Cloud Comp
Basic Analysis Twin
DMP
IOT
AI
MP

AT 2: Basic Analysis Twin

The second archetype this focused on not only storing data and allowing actors to interact with it but it's also meant as a tool for analyzing the created digital twin. To this end cloud computing and an Internet of Things connection are necessary to analyze an existing representation and to properly indicate the effect of potential changes whilst also taking into consideration external factors.

- **BIM**
- **Cloud computing**
- **3D scanning and sensors**
- **IOT**
- **Material Passports**



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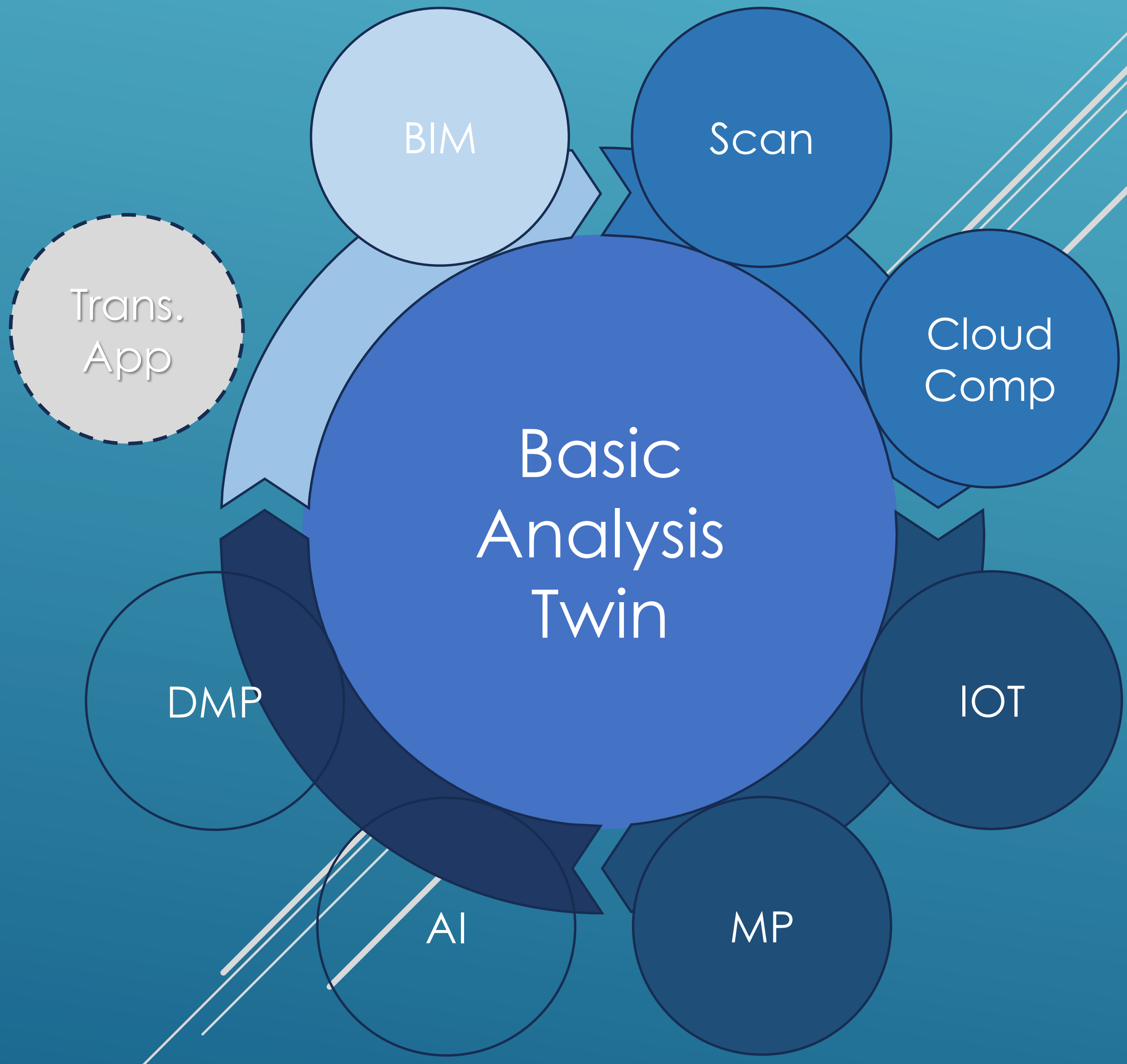

Using this setup, the digital twin can analyze patterns and provide actionable insights. For instance, it might identify that certain floors are over-lit during the day due to sunlight, suggesting that window shades and lighting adjustments could reduce energy use. Or it might detect that certain HVAC zones are heating or cooling unnecessarily, allowing for optimized scheduling based on occupancy patterns.

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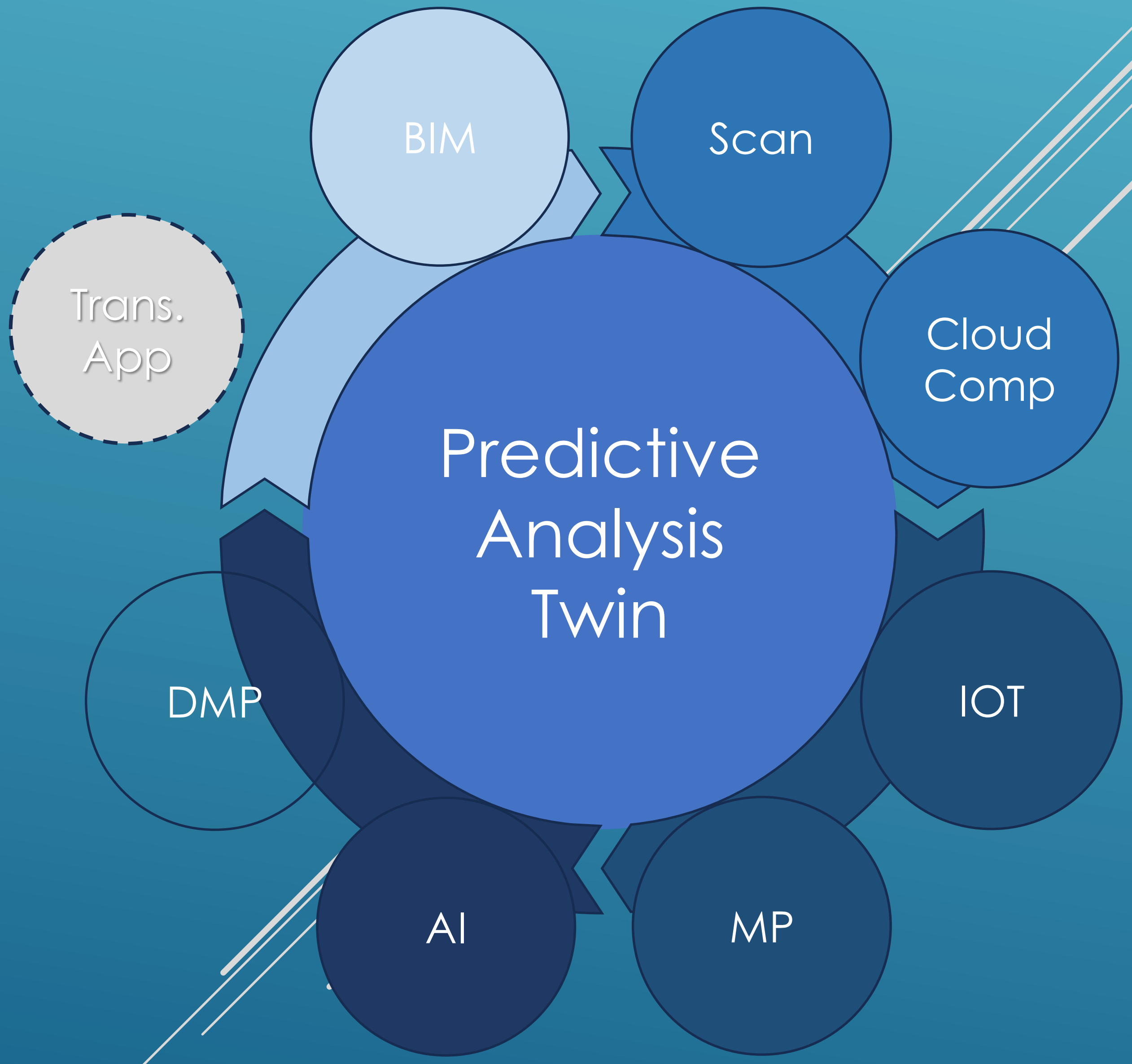
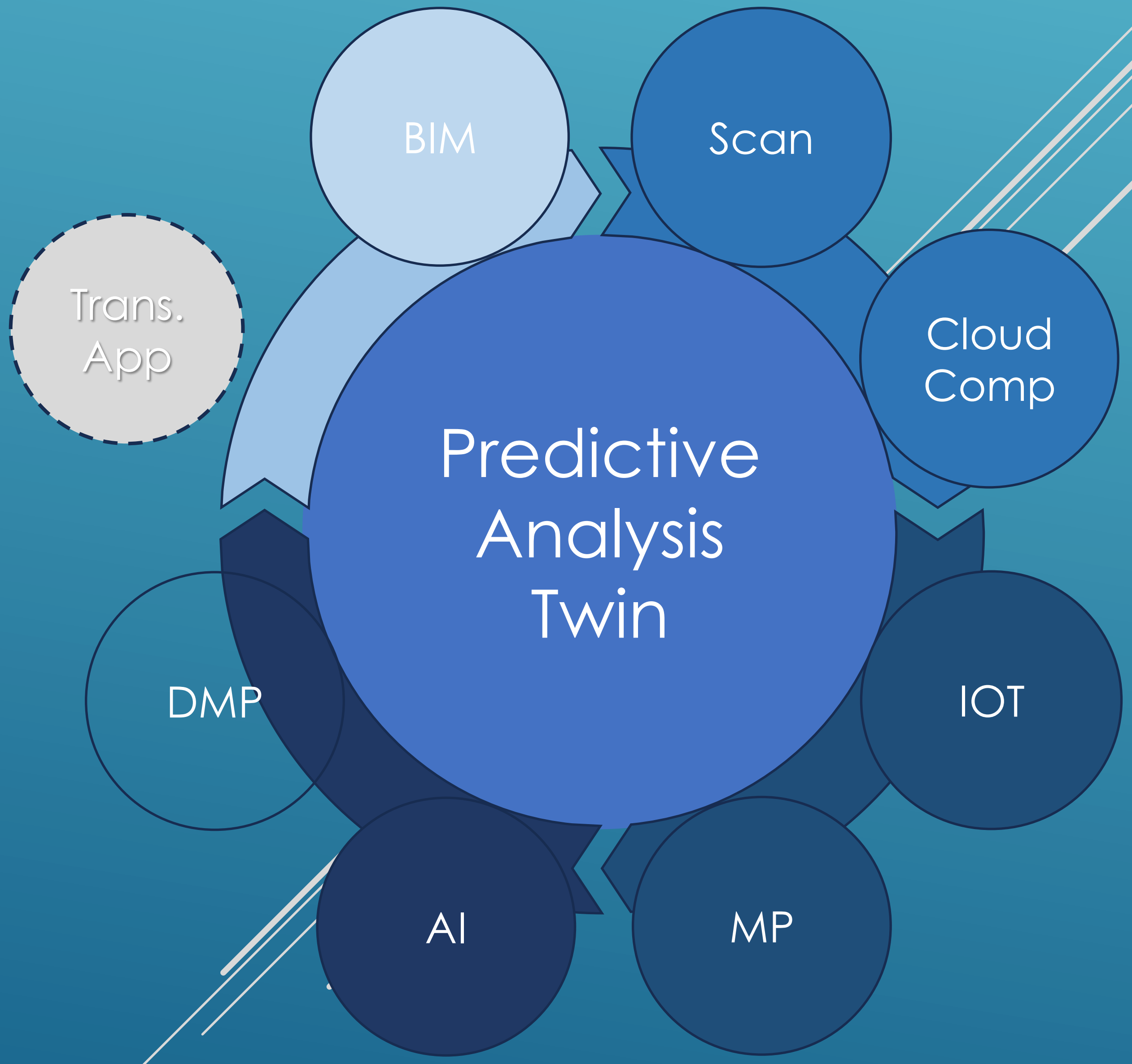
PREDICTION


BIM
Scan
Trans. App
Cloud Comp
Predictive Analysis Twin
DMP
IOT
AI
MP

AT3: Predictive Analysis Twin

The third archetypes are more advanced the goal of these types of digital twins this to add a predictive layer to the capabilities of the digital representations. These digital representations act as design, data storage, analytical and predictive tools for digital twins. AI can be used to predict the state of components and subcomponents allowing them to facilitate multiple circularity strategies.

- **BIM**
- **Cloud computing**
- **3D** scanning and sensors
- **IOT**
- **AI**



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A Predictive Analysis Twin for a building could use AI to forecast the wear and replacement needs of equipment components, optimizing maintenance schedules and extending the lifespan of machinery and the building as a whole.

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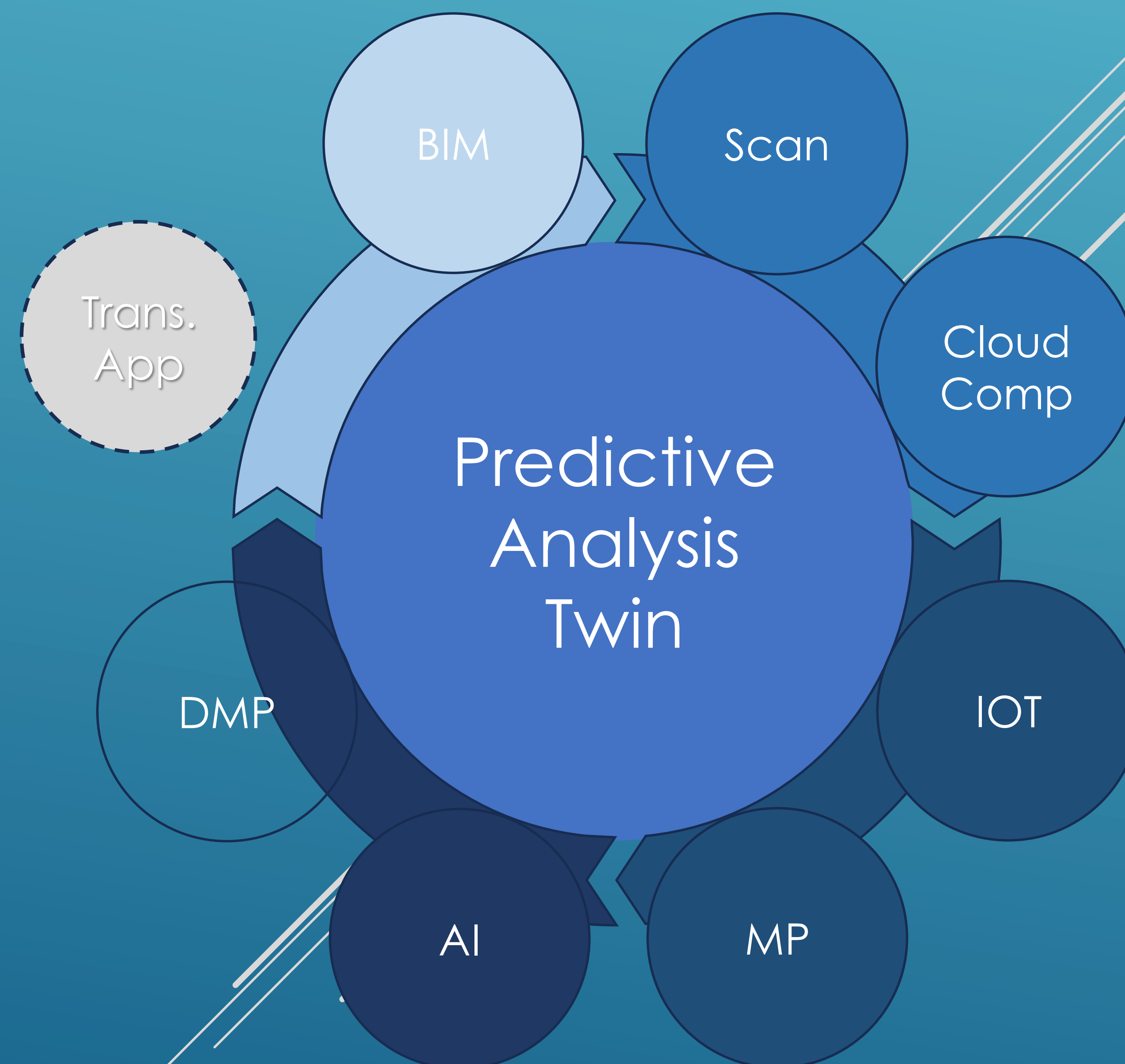
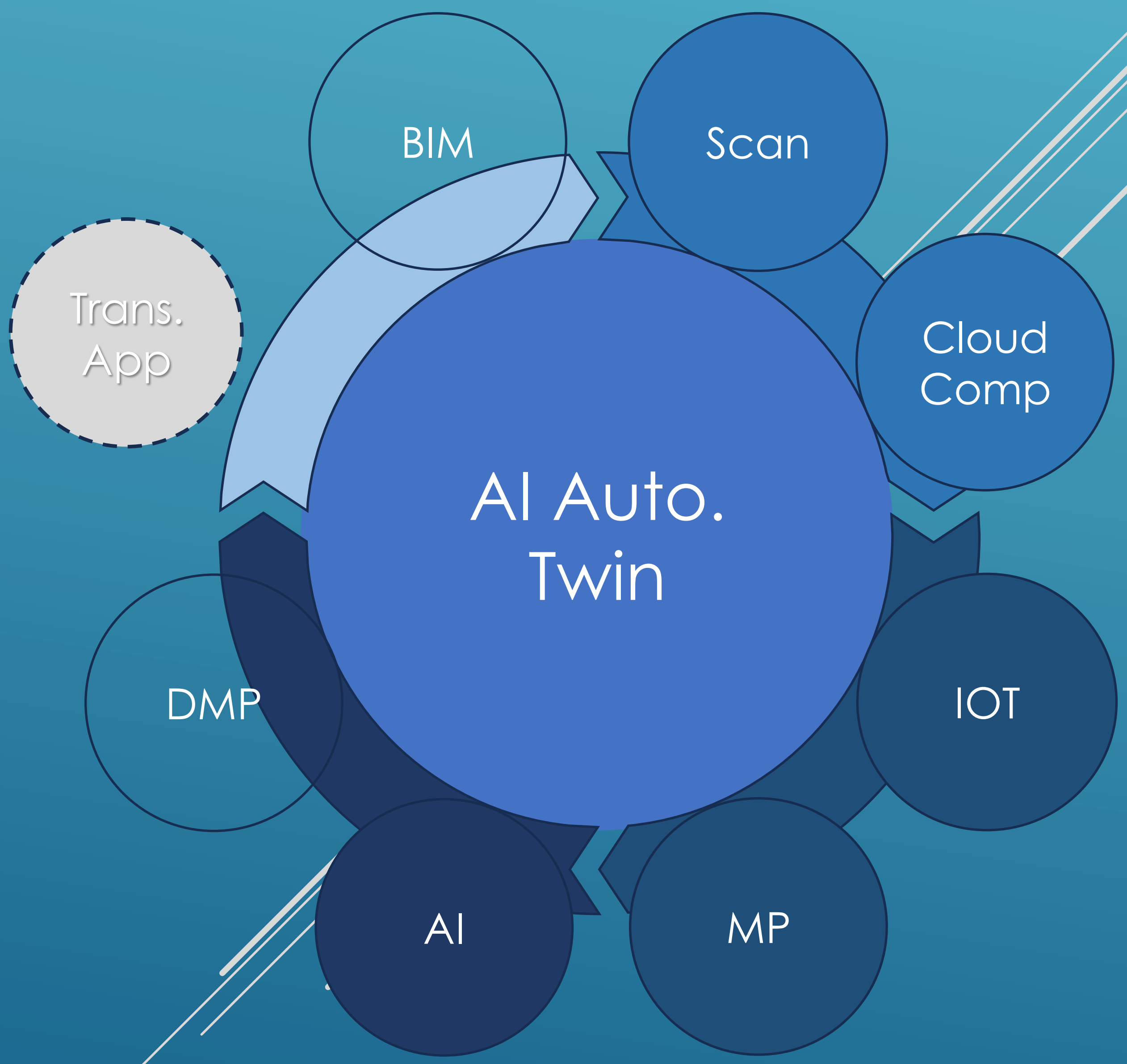


AUTOMATION



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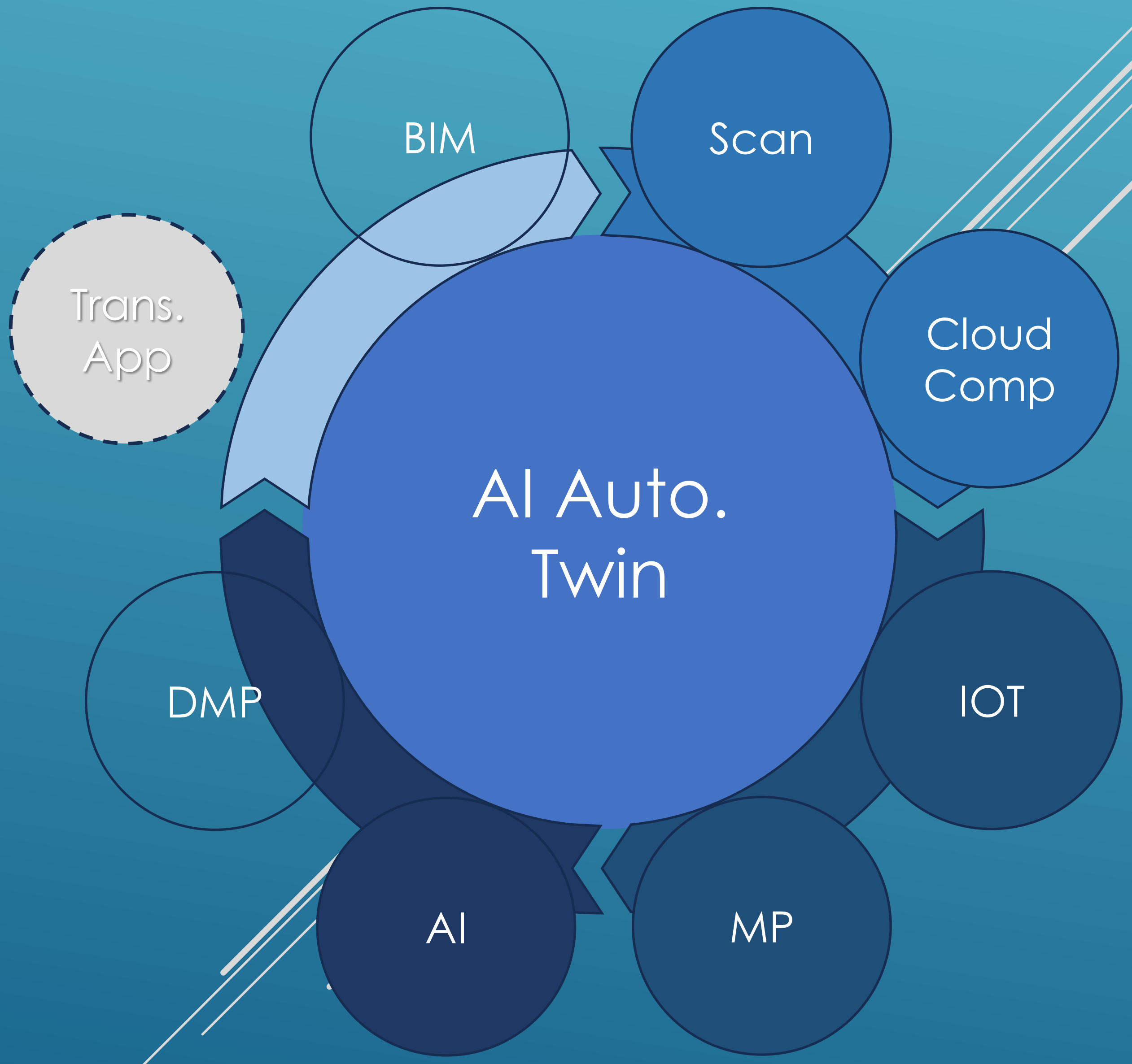
AT4: AI Automated Twins

Archetype 4 removes the human interface but adds an additional capability to share information across digital twins directly. It could facilitate data storage analysis predictions and sharing, however the use cases will be limited as in the near future it is apparently unlikely that humans will be completely removed from the processes within the built environment.

- **Cloud computing**
- **3D scanning and sensors**
- **Material Passports**
- **IOT**
- **AI**



In a smart office building, an AI automated twin optimizes HVAC settings based on real-time occupancy, saving energy and ensuring comfort. It predicts maintenance needs and alerts the management team to issues like malfunctioning sensors, allowing for quick fixes and reducing downtime. This proactive system enhances efficiency and occupant satisfaction and reduces damage and the chance for disuse.

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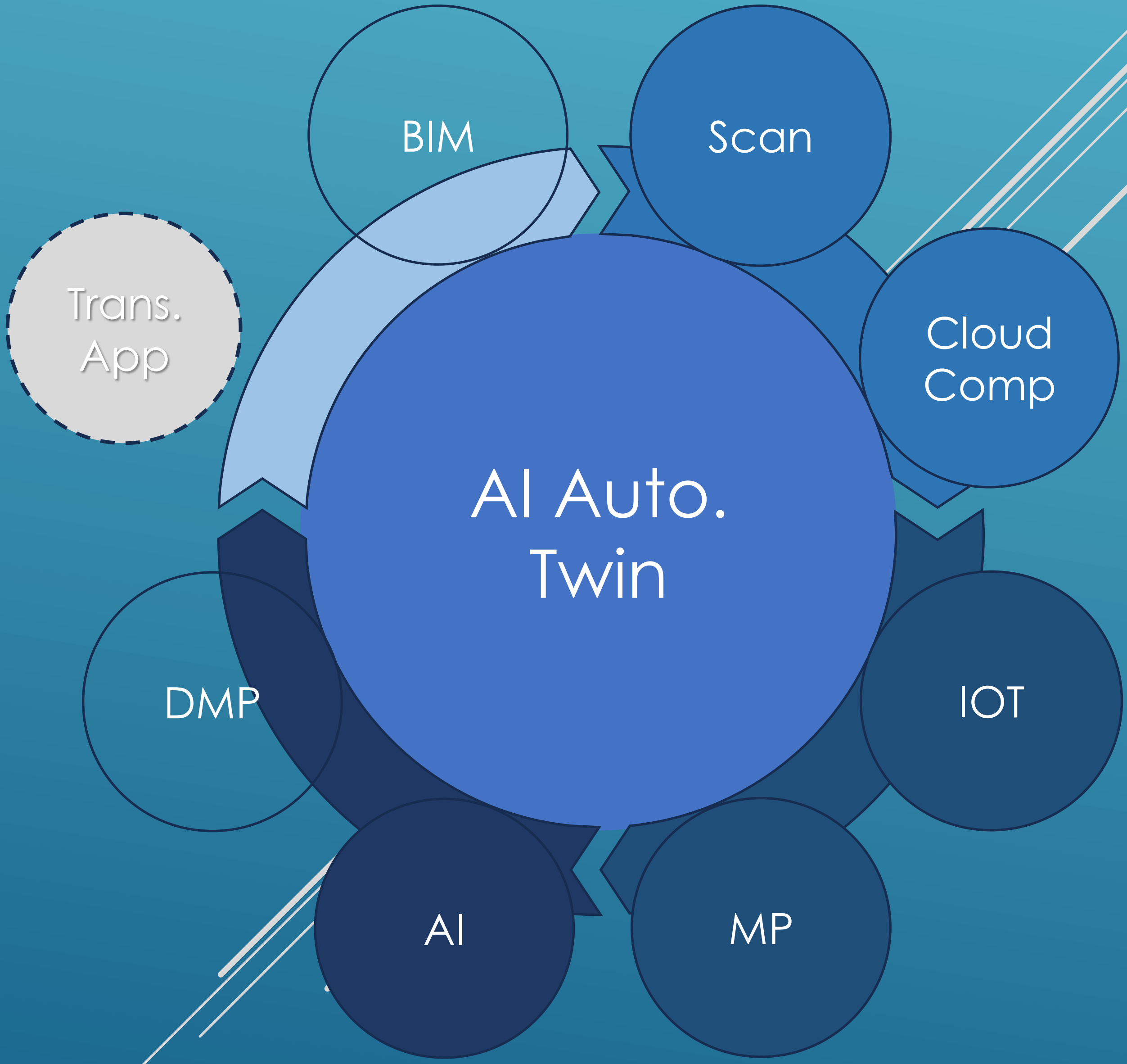
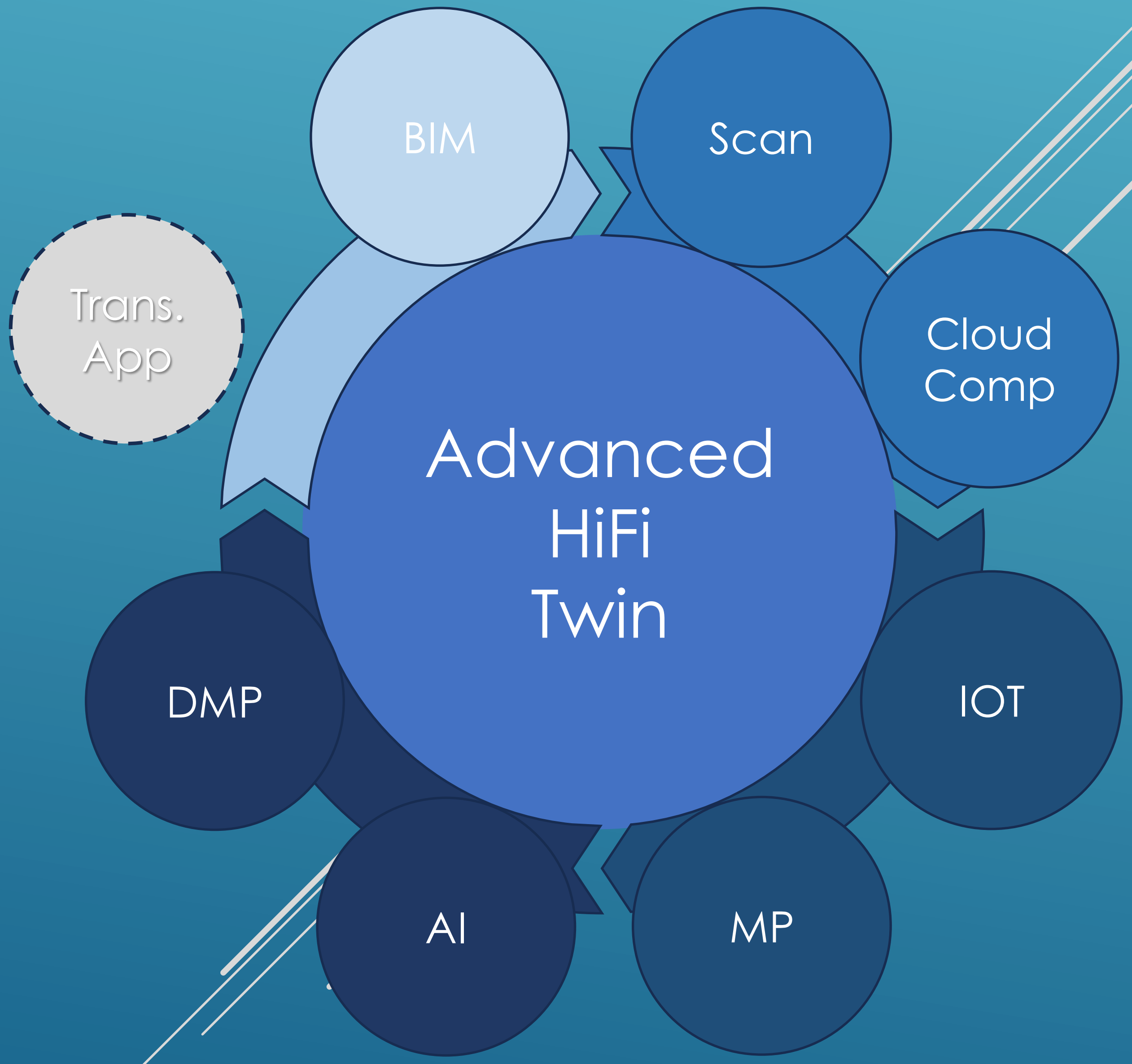


DIGITAL ECOSYSTEM INTEGRATION



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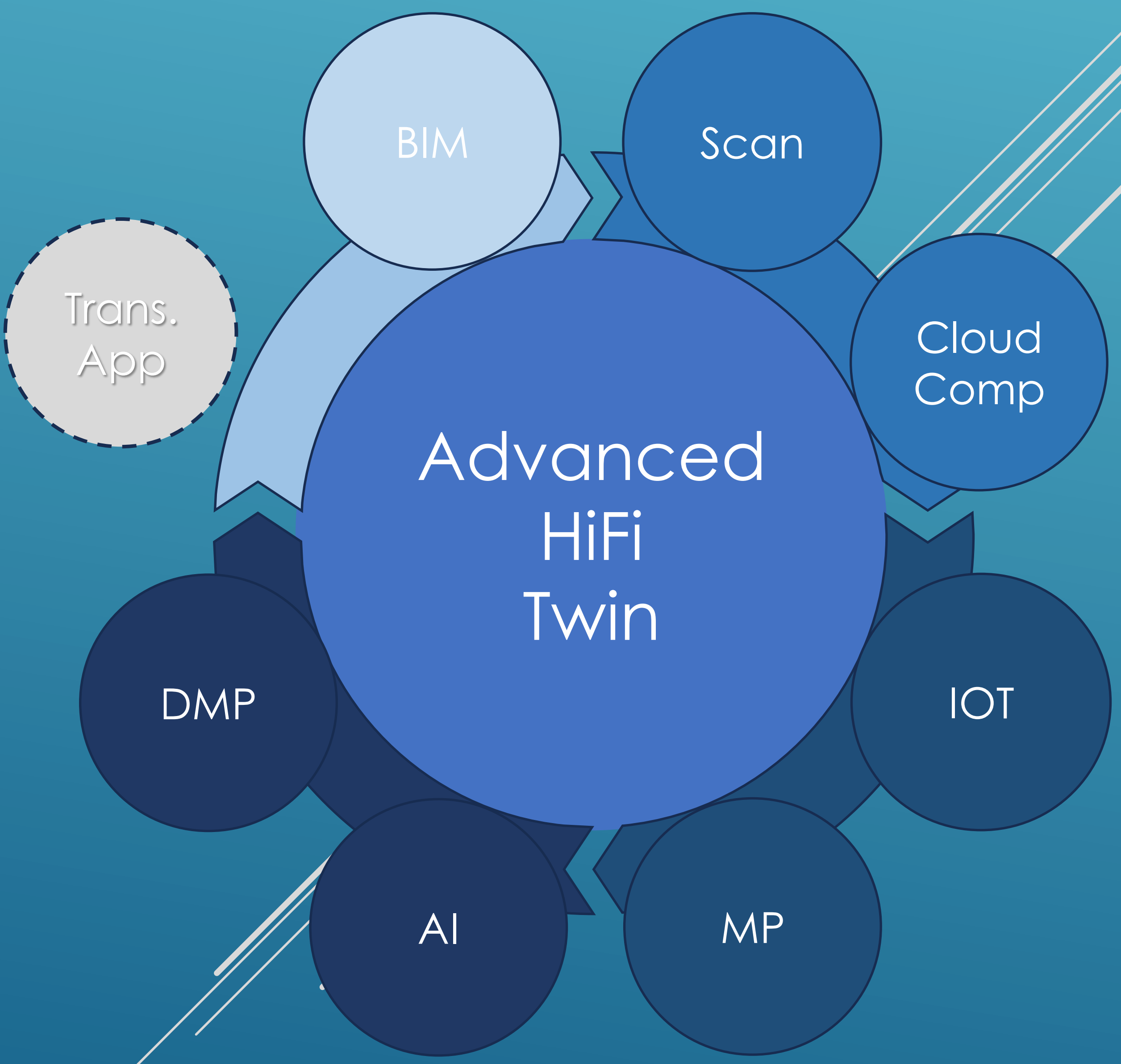
AT 5: Advanced High fidelity Twins

Architect five, as stated earlier is most comprehensive digital twin architype. This archetype much like archetype four, has the capacity to share information and integrate shared information. It's integrated AI capabilities paired with cloud computing create a powerful tool for analyzing I'm predicting component and material flows. It's capacity to share information with other machines and humans either directly or via a material platform allows for a interconnected and integrated digital twin of the larger built environment.

- **BIM**
- **Cloud computing**
- **3D** scanning and sensors
- **Material Passports**
- **IOT**
- **AI**
- **Material Platforms**



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An model that optimize the flow of materials across urban infrastructure. By integrating data from buildings, waste management, energy systems, and water resources, this digital twin enables circular practices such as reusing construction materials, recycling waste, and repurposing energy. With AI-driven insights, it forecasts resource needs, minimizes waste, and facilitates the redistribution of materials across sectors, creating a highly interconnected urban ecosystem that promotes sustainability and reduces environmental impact.

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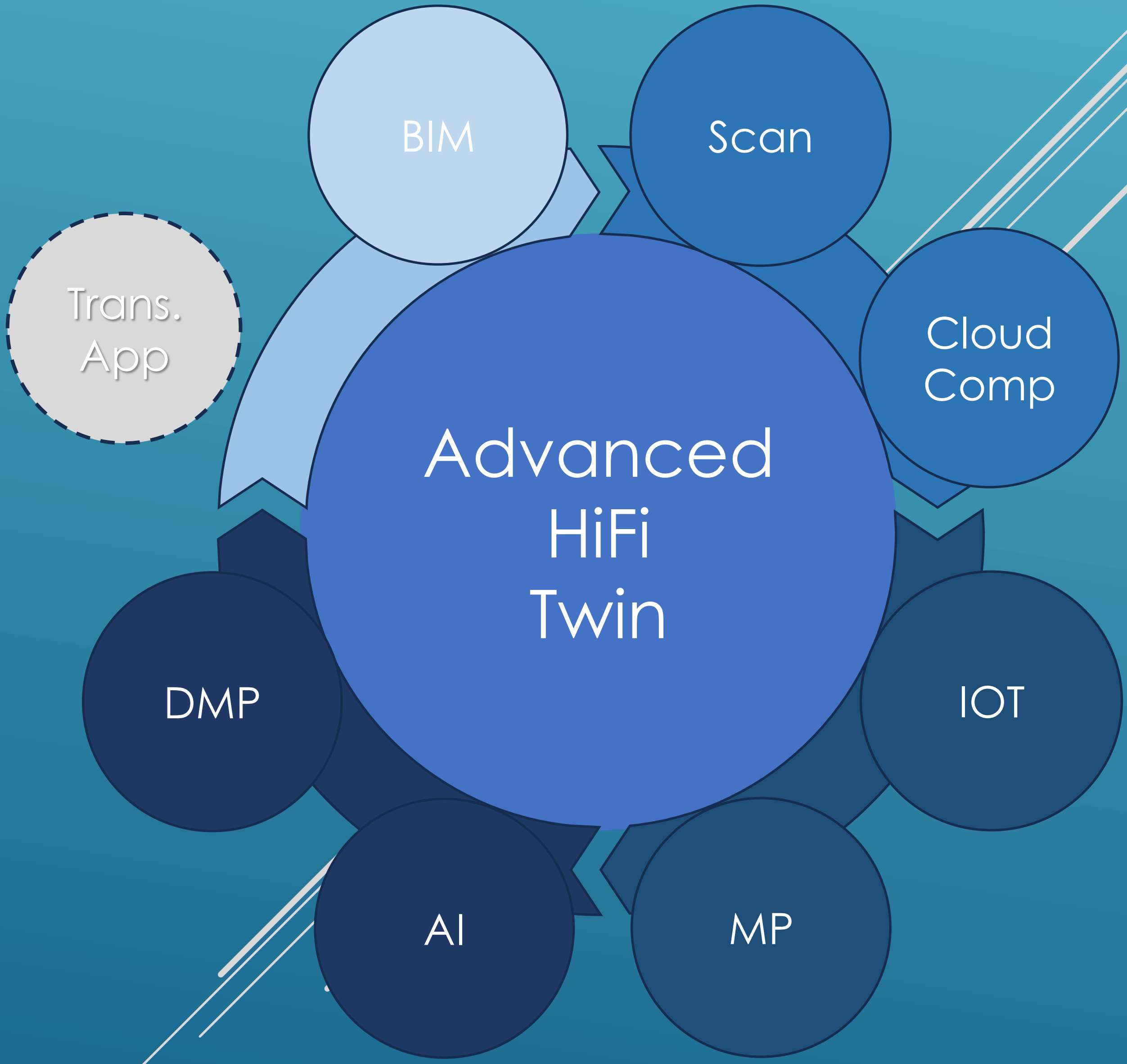

Digital technology Barriers

- Safeguarding of data and the issue of ownership
- Lack of standardized data standards and tools
- Diversity within source systems
- Financial and Economic challenges
- Cultural challenges
- Regulatory Challenges

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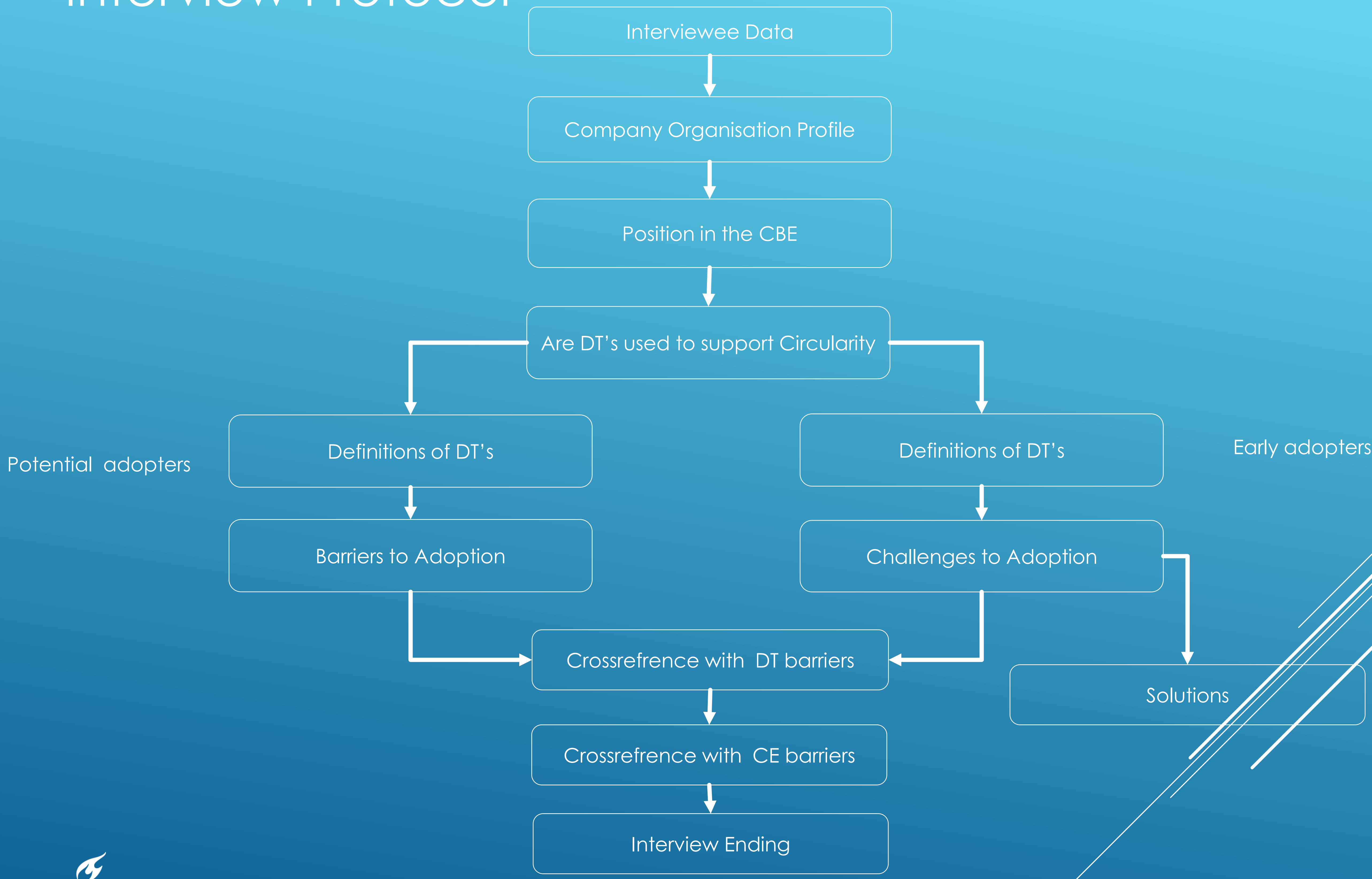
BRINGING DIGITAL TWINS AND CIRCULARITY TOGETHER

INTERVIEWS

Interview Protocol



RESULTS

Results – Usage

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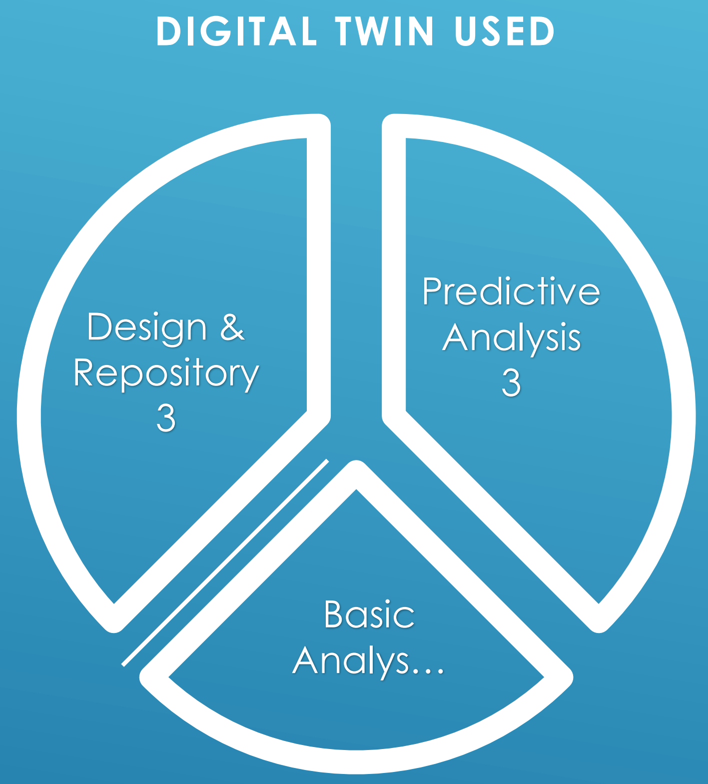
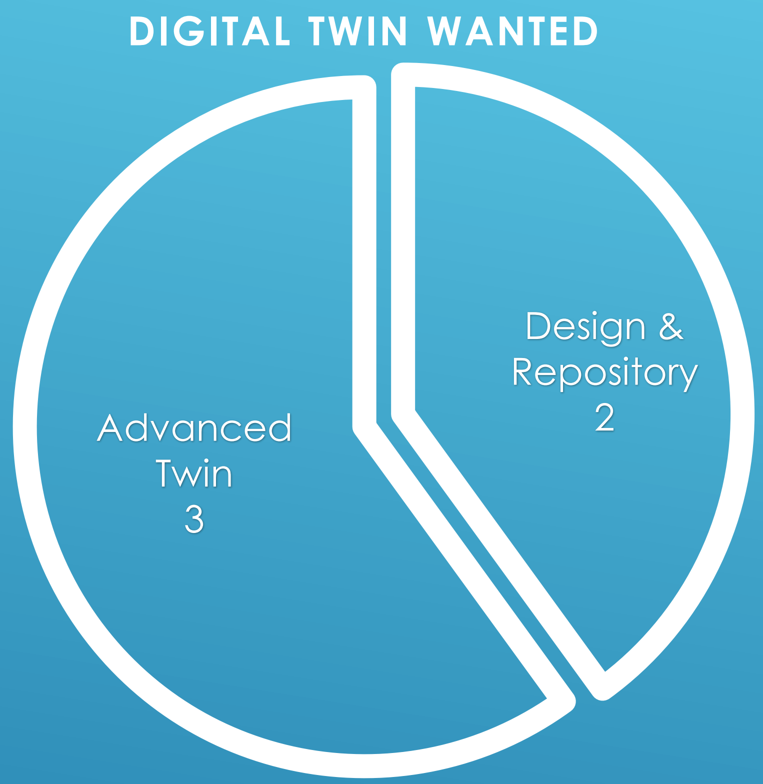
Results – Digital Twin Archetype preferences





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Results – Barriers and Challenges

	DT used										DT not used						
Interviewees	**intv. 1**	**intv. 2**	**intv. 3**	**intv. 6**	**intv. 8**	**intv. 9**	**intv. 11**	**intv. 13**	**Total Occ. Challenges**		**intv. 4**	**intv. 5**	**intv. 7**	**intv. 10**	**intv. 12**	**Total Occ. Barriers**	
Combining Data (DWSS)	0	1	0	0	1	0	1	0	3	38%	0	0	0	0	0	0	0%
Data Ownership	1	0	0	1	0	1	0	0	3	38%	0	0	0	1	1	2	40%
Data Privacy	0	0	0	0	0	0	0	1	1	13%	0	0	0	0	0	0	0%
Data Safety	0	0	0	1	0	0	0	0	1	13%	0	0	0	0	0	0	0%
Financial Capacity	1	1	1	1	0	1	0	1	6	75%	1	1	0	0	1	3	60%
Lack of Clear Buisness Models	0	1	0	1	1	0	1	1	5	63%	0	0	0	1	1	2	40%
Lack of Parties Capable of Making DT's	0	0	0	0	0	0	0	0	0	0%	0	0	0	0	0	0	0%
Regulatory challenges	1	0	1	0	0	0	1	1	4	50%	1	0	0	1	1	3	60%
Standerdisation of data	1	1	1	1	1	0	1	0	6	75%	1	1	1	0	0	3	60%
Technological Hesitancy (cultural)	1	0	1	0	1	1	0	1	5	63%	1	1	1	0	1	4	80%
Archetype Choice	AT 2	AT 2	AT 3	AT 1	AT 1	AT 3	AT 3	AT 1			AT 5	AT 1	AT 5	AT 1	AT 5		

Digital Twin Specific Barriers

- Safeguarding of data and the issue of ownership
- Lack of standardized data standards and tools
- Diversity within source systems

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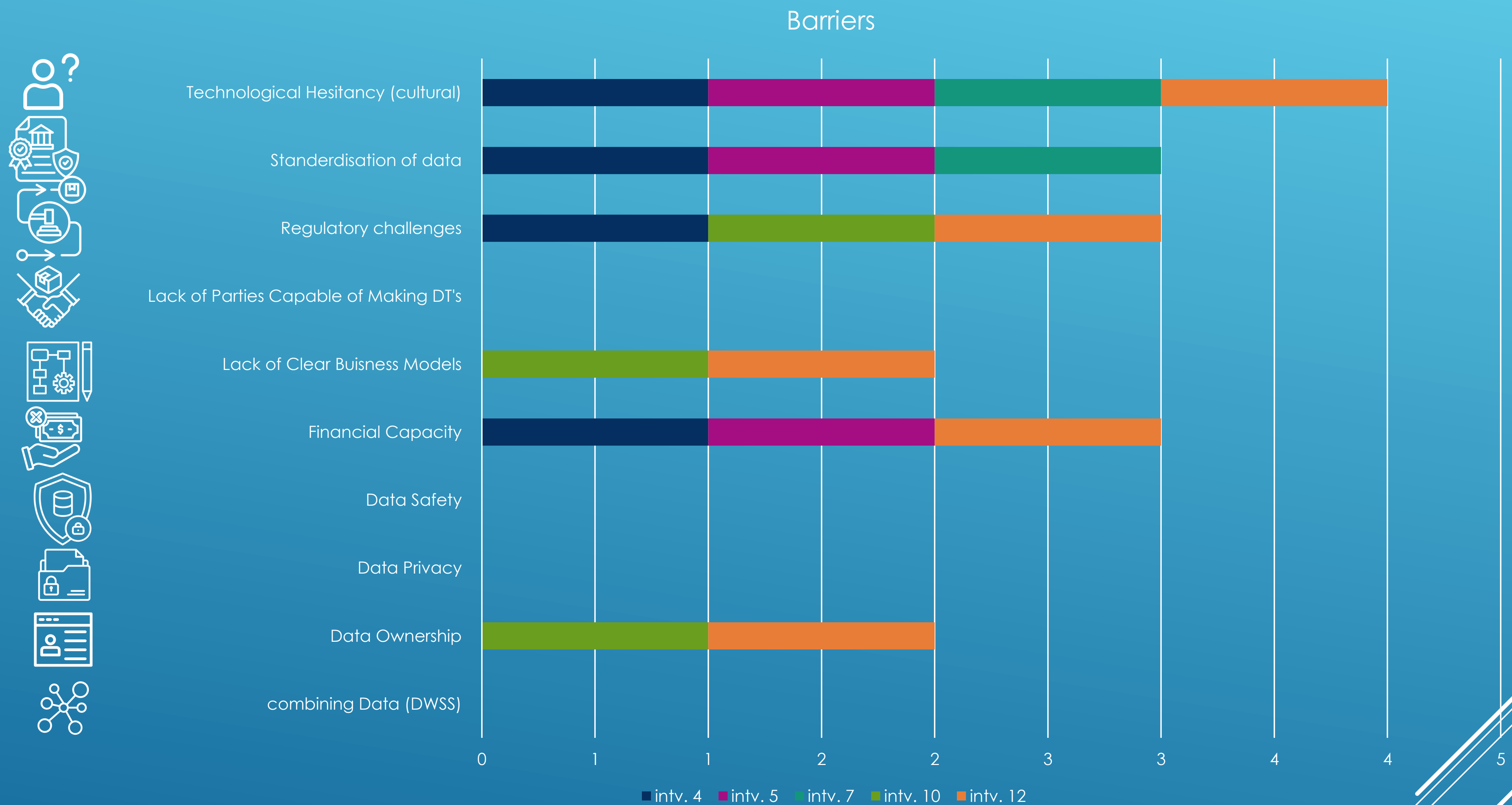
Digital Twin Specific Barriers

- Financial and Economic challenges
- Cultural challenges
- Regulatory Challenges

Results – Anticipated Barrier



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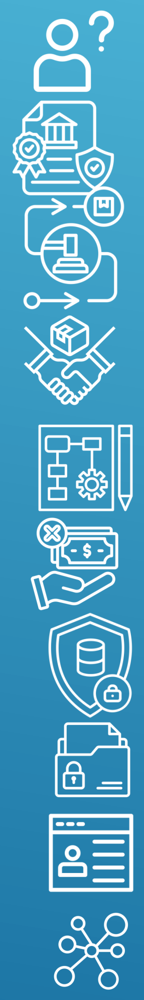
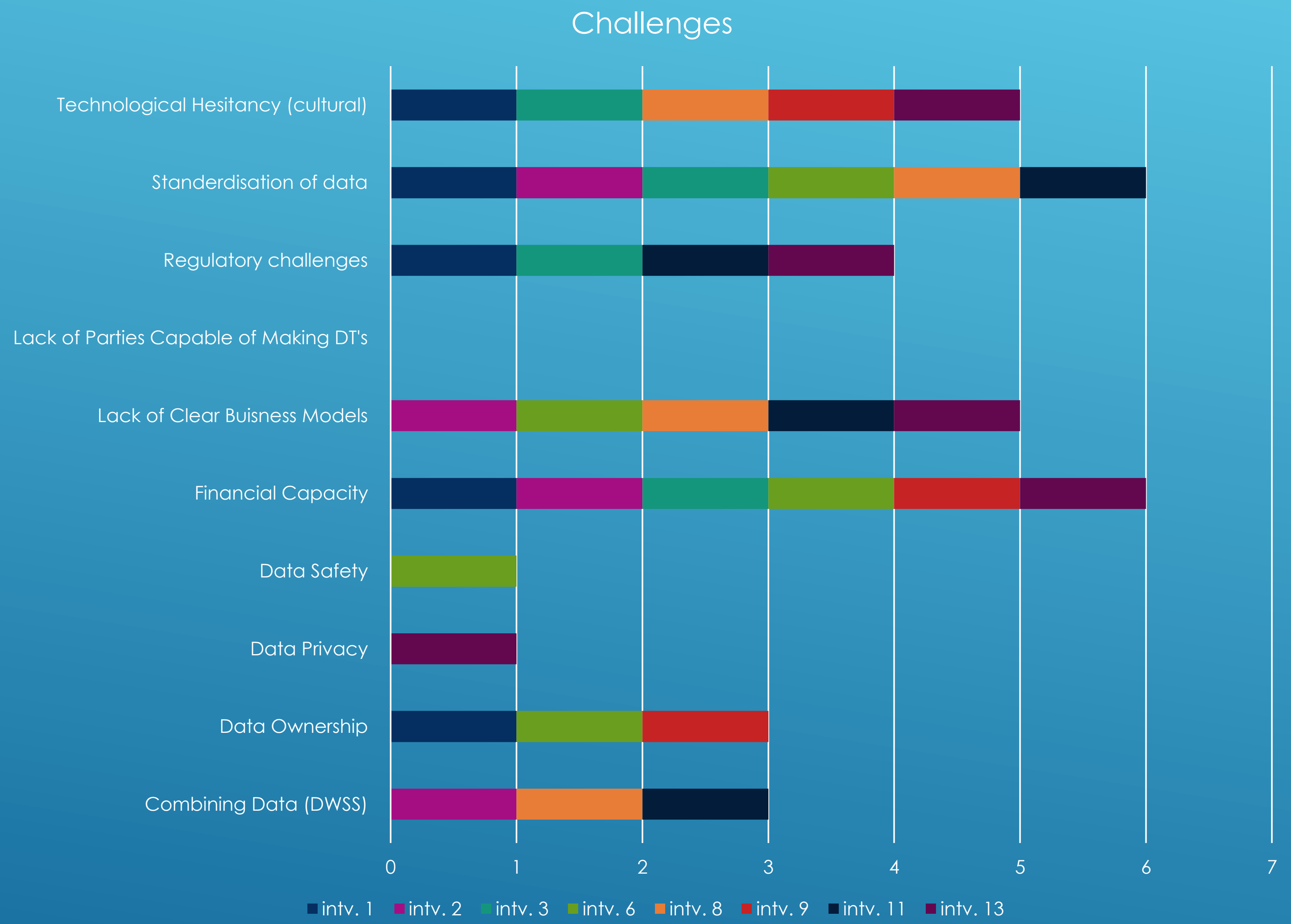
Results – Experienced Challenges





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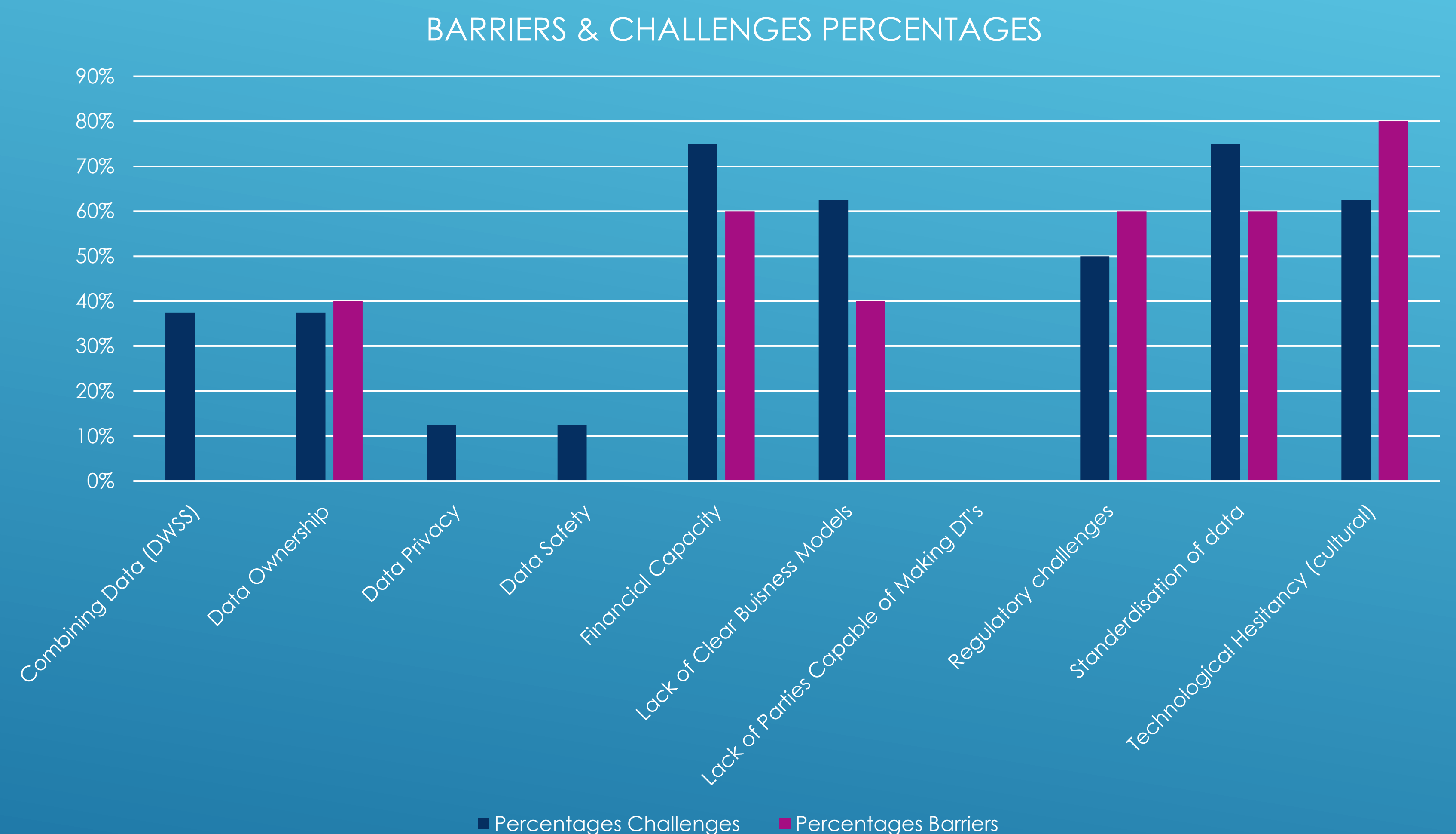
Barriers & Challenges



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Results – Solution

Solutions:

- Data standards integration (e.g., IFC protocols).
- Financial incentives tailored to customer needs.
- Stakeholder engagement, including innovation-friendly partners.
- Addressing regulatory gaps through government collaboration.
- Using current technology as a starting point
- Technological iteration and improvements.

DISCUSSION

Key Insights – Early Adopters

1. Adoption of Archetype 1

- **Characteristics:**
  - Preferred by younger, innovation-driven companies.
  - Often used by **technology service providers**.
  - Seen as a **less mature model**, ideal for smaller organizations.

2. Adoption of Archetype 2 & 3

- **Characteristics:**
  - Used by larger organizations or those with specialized functions.
  - Require **higher financial** or **technical capacity**.
  - More complex in nature compared to Archetype 1.

3. Evolution after **Adoption**

- **Transition:**
  - Companies using Archetype 1 aim to eventually move to more advanced models.
- **Development Approach:**
  - Starting with basic models and modifying them to meet specific needs.
  - Gradually evolving into more **mature** and **capable** archetypes.

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Key Insights – Potential Adopters

1. Complexity of the Archetype

- **Archetype 1 (AT1):**
  - Chosen for **simplicity**, ease of adaptability, and implementation.
- **Archetype 5 (AT5):**
  - Preferred for handling **complex real-time data** and **advanced capabilities**.

2. Organizational Perspective

- **AT1:**
  - Narrow focus (e.g., interiors, specific research).
- **AT5:**
  - Broader operational profile (e.g., sustainability, lifecycle management).

3. Technology-Oriented Perspective

- **AT1:**
  - Seen as a starting point, particularly for **shorter life cycles**.
- **AT5:**
  - Preferred for **advanced integration** and ability to connect with broader ecosystems.
  - **Key Insight:** Most interviewees wanted to adopt AT5 as a **ready-to-use package** rather than developing it themselves.

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Key Insights – PA vs EA

1. Key Factors in Archetype Selection

- **Organization Size & Specialization:**
  - Larger organizations tend to adopt **Archetypes 2 & 3**.
  - Require financial and technological resources for **complex functionalities** like predictive analysis.

2. Early Adopters of Archetype 1

- **Characteristics:**
  - Smaller, innovation-driven, or technical service organizations.
  - **Archetype 1** offers a flexible, foundational model that is easier to deploy and requires lower initial investment.
  - Ideal for **quick adaption** and shorter life cycles (e.g., interior design, research institutions).

3. Prospective Adopters of Archetype 5

- **Key Features:**
  - Prioritize sustainability, circular economy, and **complex material management**.
  - Require sophisticated real-time data handling and integration with AI.
- **Challenges:**
  - Seen as **ambitious** due to the need for significant infrastructure and development resources.

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Barriers & Challenges

	DT used		
Interviewees	intv. 6, 8 & 13	intv. 1 & 2	intv. 3, 9 & 11
Combining Data (DWSS)	1	1	1
Data Ownership	1	1	1
Data Privacy	1	0	0
Data Safety	1	0	0
Financial Capacity	2	2	2
Lack of Clear Buisness Models	3	1	1
Lack of Parties Capable of Making DT's	0	0	0
Regulatory challenges	1	1	2
Standerdisation of data	2	2	2
Technological Hesitancy (cultural)	2	1	2
Archetype Choice	AT 1	AT 2	AT 3

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Barriers & Challenges

	DT wanted	
Interviewees	intv. 5 & 10	intv. 4, 7 & 12
Combining Data (DWSS)	0	0
Data Ownership	1	1
Data Privacy	0	0
Data Safety	0	0
Financial Capacity	1	2
Lack of Clear Buisness Models	1	1
Lack of Parties Capable of Making DT's	0	0
Regulatory challenges	1	2
Standerdisation of data	1	2
Technological Hesitancy (cultural)	1	3
Archetype Choice	AT 1	AT 5

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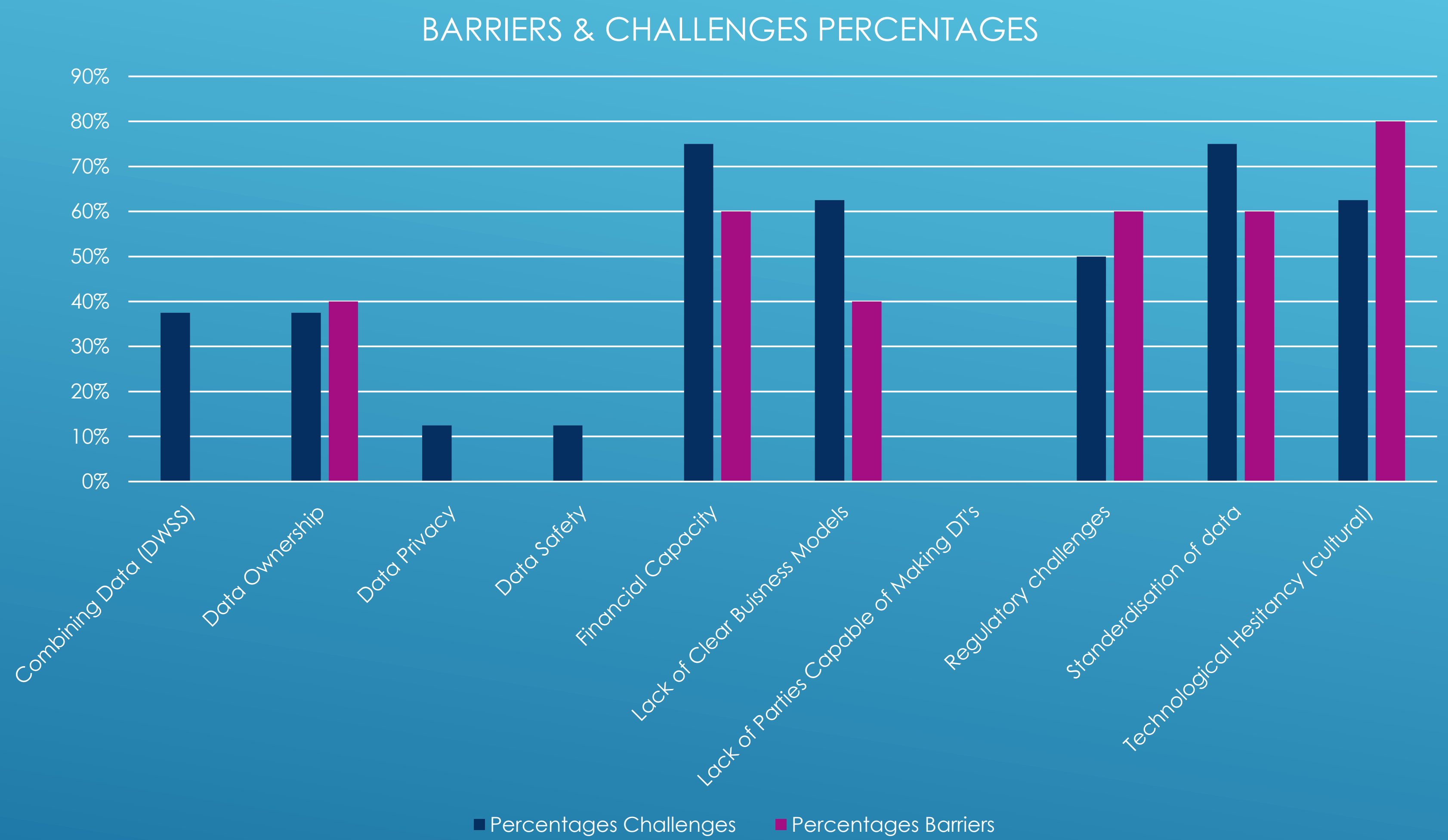
Barriers & Challenges



Solutions vs Unresolved Challenges

1. Data Standards and Integration

- **Key Solutions:**
  - Develop communication and data-sharing protocols.
  - Create a common ontology and computational language.
  - Expand IFC standards to reduce fragmentation.
  - Link data flows to IFC in recycling processes.

2. Technology and Tools

- **Key Solutions:**
  - Iterative technology improvements.
  - Use enriched IFC models for onsite data generation.
  - Implement step-by-step approaches for specific use cases.

3. Financial Incentives and Business Models

- **Key Solutions:**
  - Align financial incentives with customer demands.
  - Develop self-financing models to mitigate external constraints.

4. Stakeholder Engagement and Change Management

- **Key Solutions:**
  - Educate stakeholders on the benefits of Digital Twins.
  - Select partners open to innovation.

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Solutions vs Unresolved Challenges

- **Unresolved Challenges:**
  - Data ownership issues still present.
  - Cultural hesitancy persists.
  - Financial constraints still hinder adoption.
  - Lack of comprehensive regulatory frameworks .
- **Unaddressed Challenges:**
  - Lack of capable market partners .
  - Insufficient focus on data privacy and security .

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Digital Twins in the CBE – Key take aways

1. Importance of DCBE

- **Crucial Role:**
  - Essential for achieving circularity.
  - Helps overcome barriers in implementing Digital Twin functions in circular systems.

2. The Challenge of Generic Archetypes

- **Issue:**
  - Generic archetypes often unsuitable for specific technologies and companies.
- **Catch 22 Scenario:**
  - The Circular Built Economy (CBE) is not fully established, complicating the formation of **Digital Circular Business Economy (DCBE)**.
  - Represents a **chicken and egg** problem.
- **3. Technology and Tools**
- **Incorporating Digital Twin Technology:**
  - Emphasizes the need for a **methodical and iterative approach** is used by those employing digital twin technology and wanted by those that want enter the space .

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Digital Twins in the CBE – Key take aways

3. Financial Incentives and Business Models

- **Economic Focus:**
  - Develop reward systems, business rationales, and regulatory frameworks to encourage adoption.
  - Align financial methods with circular objectives for sustainable outcomes.

4. Stakeholder Engagement and Change Management

- **Strategic Communication:**
  - Importance of educating and involving both internal and external stakeholders in the digital transition.
  - Necessity for the sector to embrace evolving technologies.

5. Regulatory and Legal Aspects

- **External Considerations:**
  - Government regulations and data protection issues.
  - Development of legal frameworks is pivotal for the integration of digital twins in circular operations.

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CONCLUSION

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Conclusion

Research Question: What are the observed and anticipated barriers and challenges for early and potential adopters of Digital Twin technologies in the Dutch circular-built environment?

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Conclusion-SQ 1

Definition: Based on Bartuka (2007), built environment includes human-made products and structures as part of a larger non-built context.

Structure of the Built Environment:Change initiation → Strategic planning → Design → Construction → Use → Decommissioning(Phases identified in the research)

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Conclusion-SQ 1

Circularity Characteristics: Frame works for a Optimizing resource use Recirculating resources Regenerative properties Extended life cycles

Barriers to Circularity: Cultural, Market, Knowledge, Financial, Management, Regulatory, Technological, Supply Chain, Environmental

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Conclusion-SQ 2

Definition: Digital Twins as a network of technologies that creates a virtual representation that integrates and synchronizes physical and digital data.

Archetypes of Digital Twins: Design & Repository Twin Basic Analysis Twin Predictive Analysis Twin AI Automated Twin Advanced High-Fidelity Twin

Conclusion-SQ 3

Key Barriers Identified (Early Adopters):

•Lack of standardization
•Financial capacity challenges
•Technological hesitancy
•Regulatory issues
•Data ownership challenges

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Conclusion-SQ 3

Key Barriers Identified (Potential Adopters):

- Lack of financial capacity
- Regulatory challenges
- Technological immaturity
- Lack of a clear business model
- Cultural hesitancy within the industry

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Conclusion-SQ 3

Shared Barriers&Challenges:
•Data ownership & scarcity (40%)
•Financial capacity challenges (60%)
•Lack of clear business model (40%)
•Regulatory challenges (50-60%)
•Standardization issues (75% early, 60% potential)

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Conclusion-SQ 4

Solutions Identified:
- Leadership in communication & BIM protocols
- Iterative technological improvement
- Change management
- Modular, scalable solutions
- Open standards (e.g., IFC)
- Collaborative innovation & knowledge sharing

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CONCLUSION

CONCLUSION

Digital twins are a network of technologies that create a digital replication of a structure, resembling reality to a certain degree. They are essential tools for enabling circularity**. Early adopters** of digital twins reported challenges such as ***standardization of practices and processes, lack of financial capacity, technological hesitancy, lack of a clear business model, technological immaturity, and regulatory challenges***. **Solutions** for these challenges include leadership in communication, standardizing software, continuous technological improvements, project organization and financing, collaboration, scalable solutions, and customer-involved innovations. **Potential adopters** PRECIEVED A SIMILAR barrier PROFILE However***, challenges related to combining different data types were not significant barriers for potential users.*** Challenges such as data ownership, privacy, financial capacity and regulations were not resolved and require.

Questions?