Developments towards the munition storage depot of the future

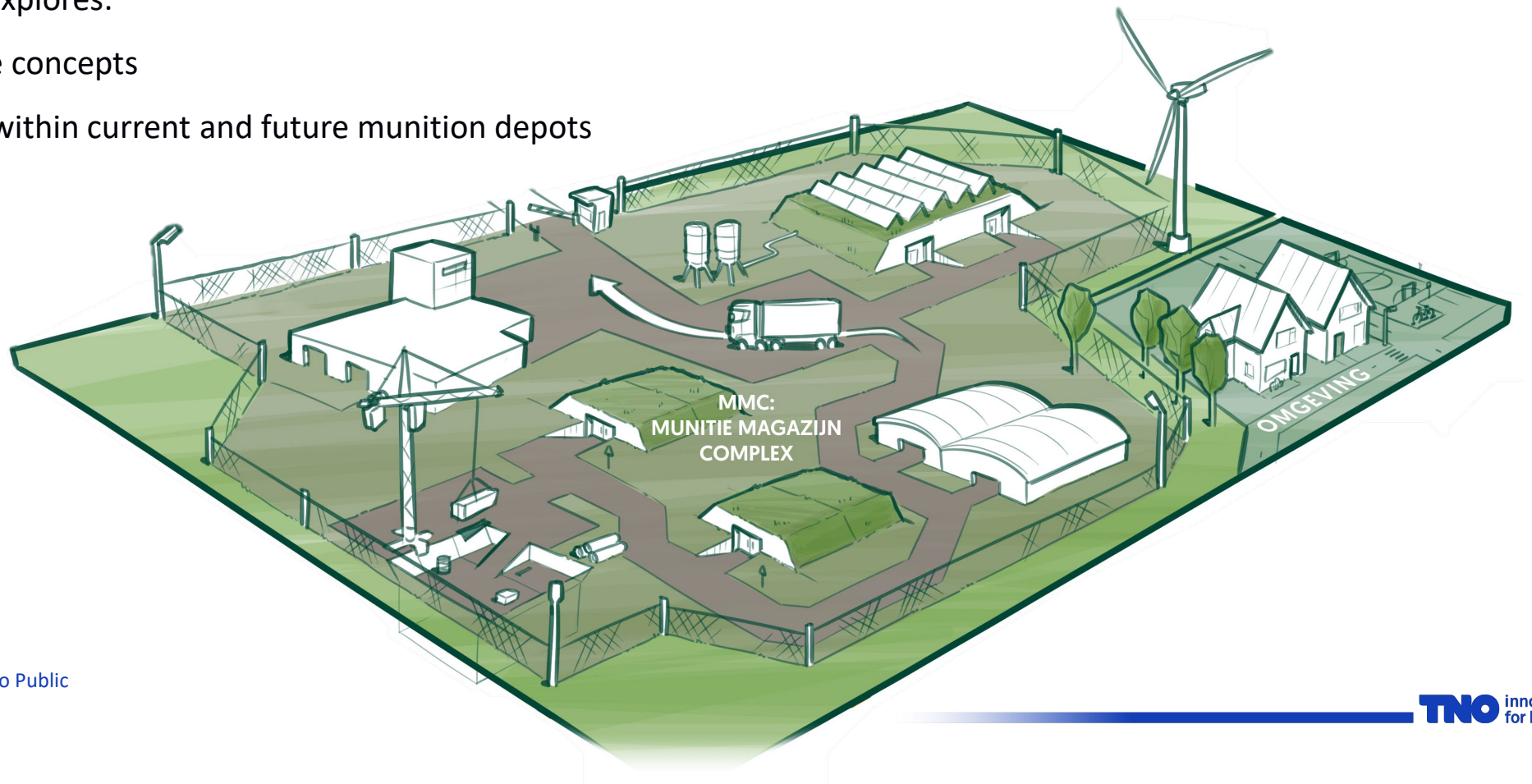
IESS 2026 | Phoenix, AZ

Yinte Verberne, Sander Schouwenaars, Dieter van der Pol, Martijn van der Voort, Hugo Dijkers - *TNO Defense, Safety and Security*

TNO innovation for life

Introduction

- TNO supports the Dutch MoD in the development of future munition storage depots
- Relevant given the growing need for storage capacity and associated spatial planning issues in the Netherlands
- The research explores:
  - New storage concepts
  - Integration within current and future munition depots



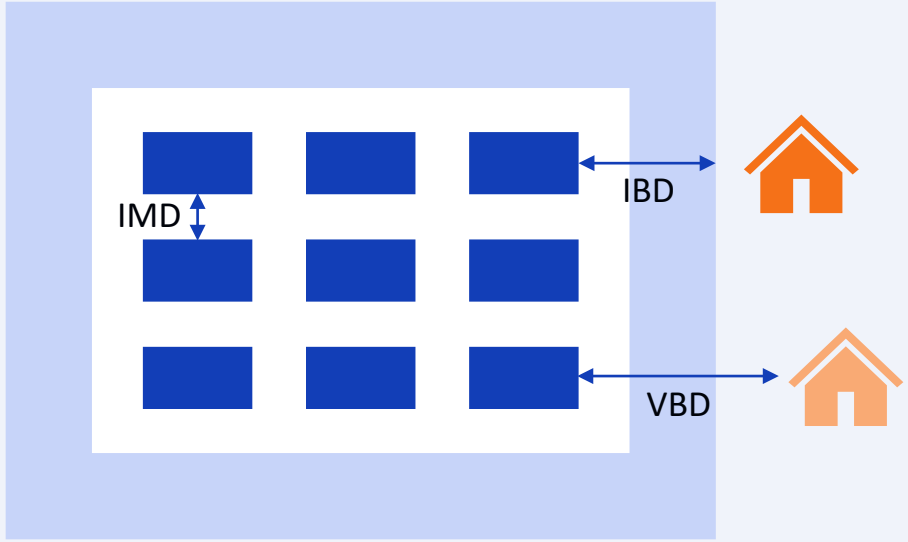
Introduction

Goal:

"Challenge conventional munition storage depot designs by introducing **innovative magazine concepts and integrated layouts**, aimed at reducing safety distances and maximizing storage capacity"

The spatial footprint of a munition storage site is largely defined by:

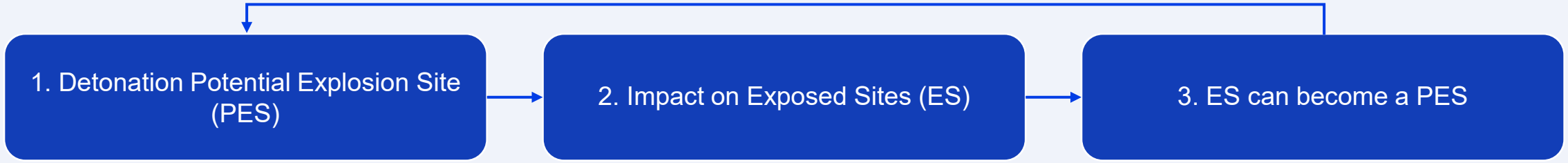
- The physical area occupied by the site itself
- Safety zones defined by NATO AASTP-1
  - Inter-Magazine Distance (IMD)
  - Inhabited Building Distance (IBD)
  - Vulnerable Building Distance (VBD)



Introduction

Current Design Principles:

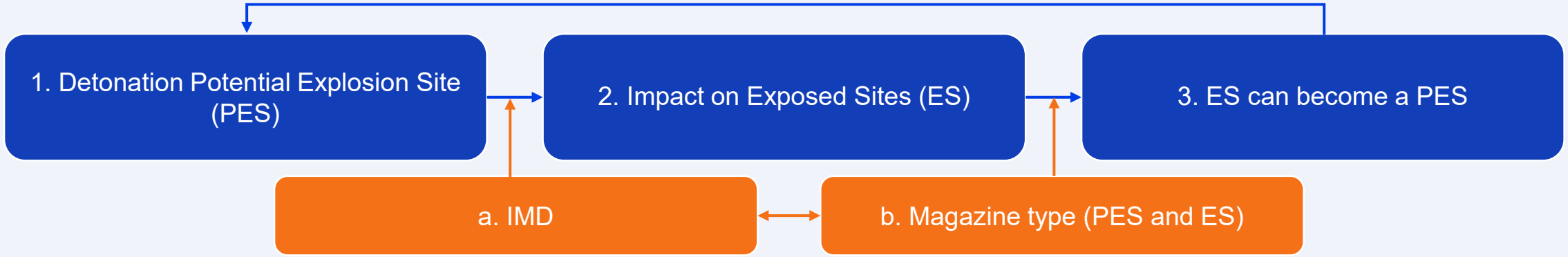
- Munition storage depots are designed to ensure internal safety
  - An Exposed Site (ES) can become a Potential Explosion Site (PES)
  - Cascading effects from multiple ES are **prevented** by design (IMD)



Introduction

Current Design Principles:

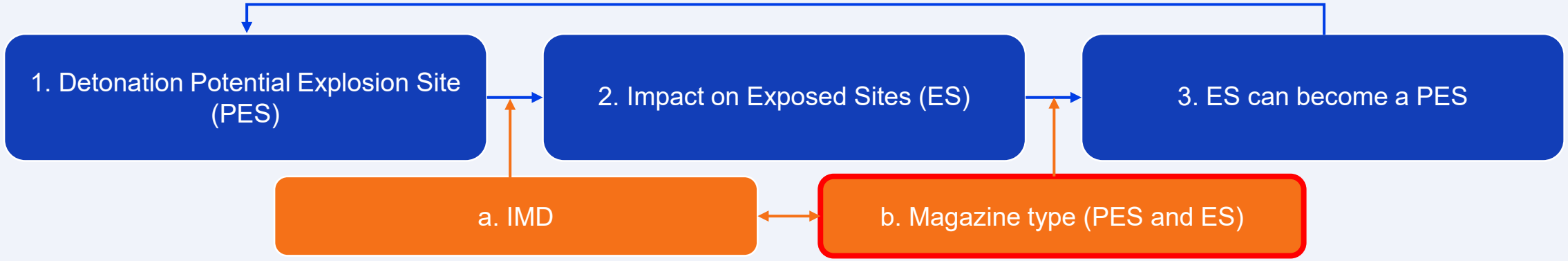
- Munition storage depots are designed to ensure internal safety
  - An Exposed Site (ES) can become a Potential Explosion Site (PES)
  - Cascading effects from multiple ES are **prevented** by design (IMD)



Introduction

Current Design Principles:

- Munition storage depots are designed to ensure internal safety
  - An Exposed Site (ES) can become a Potential Explosion Site (PES)
  - Cascading effects from multiple ES are **prevented** by design (IMD)

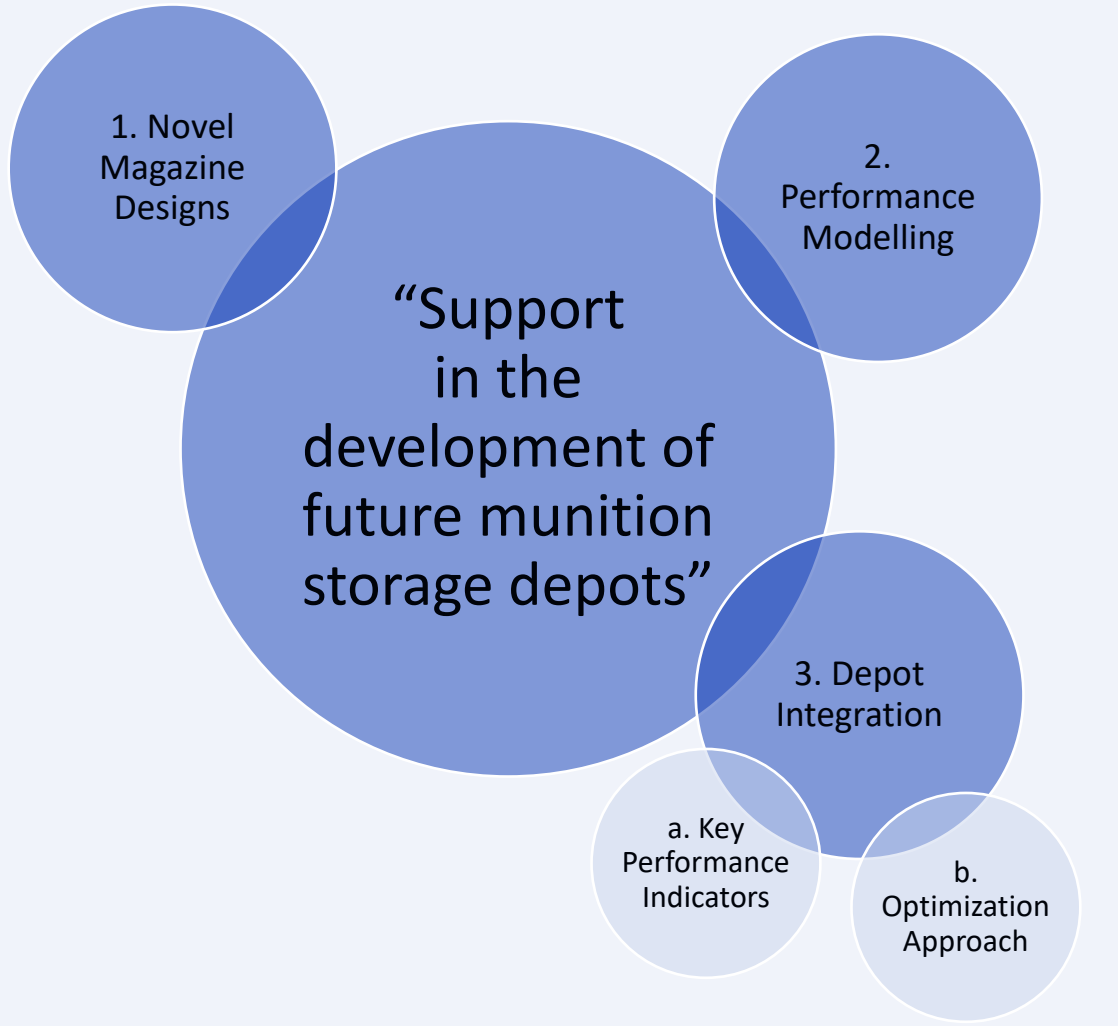


Importance Munition Magazine Design:

- Impacts PES and ES performance
- Determines prescribed safety distances, which impact the spatial footprint of the depot

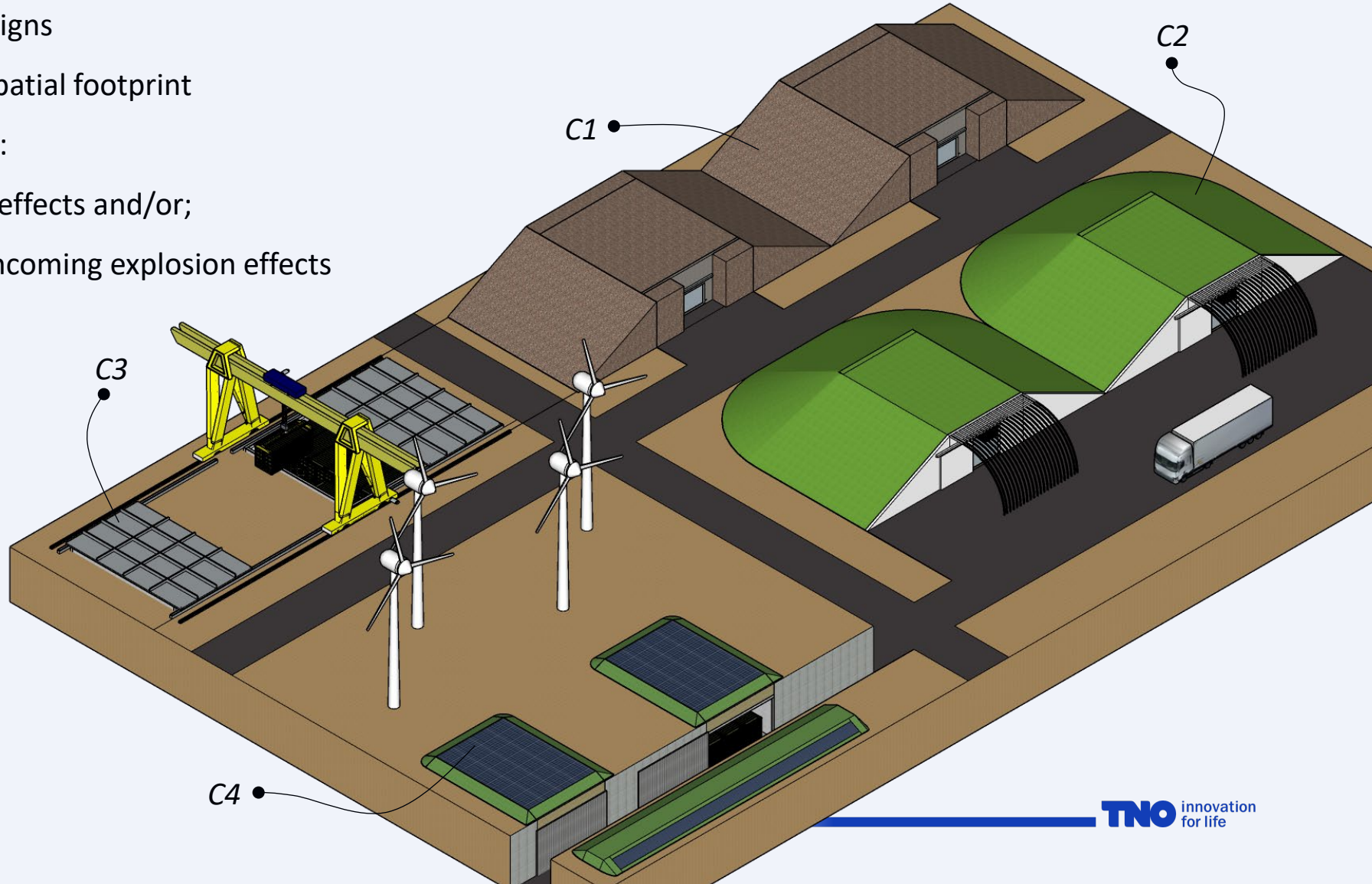
Approach

- Multi-step approach to:
  - Advance understanding of future munition storage depots
  - Meet emerging defense needs
  - Stimulate international dialogue and feedback



1. Novel magazine designs

- Challenge conventional ECM designs
  - Reduce safety distances and spatial footprint
- Four new concepts which aim to:
  i. Mitigate outgoing explosion effects and/or;
  ii. Increase resistance against incoming explosion effects
- Approach:
  - Innovative geometries
  - Novel materials



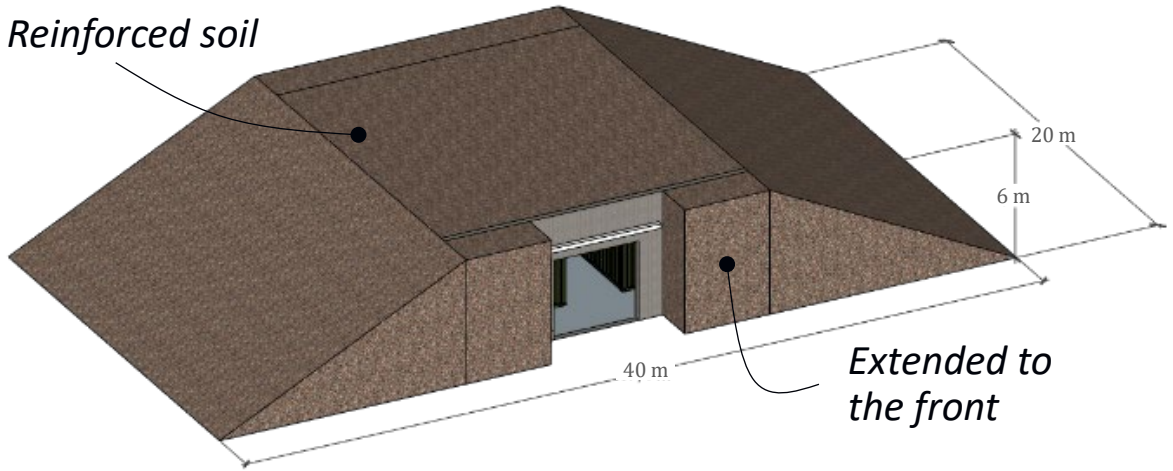
Design 1: Stabilized earth magazine

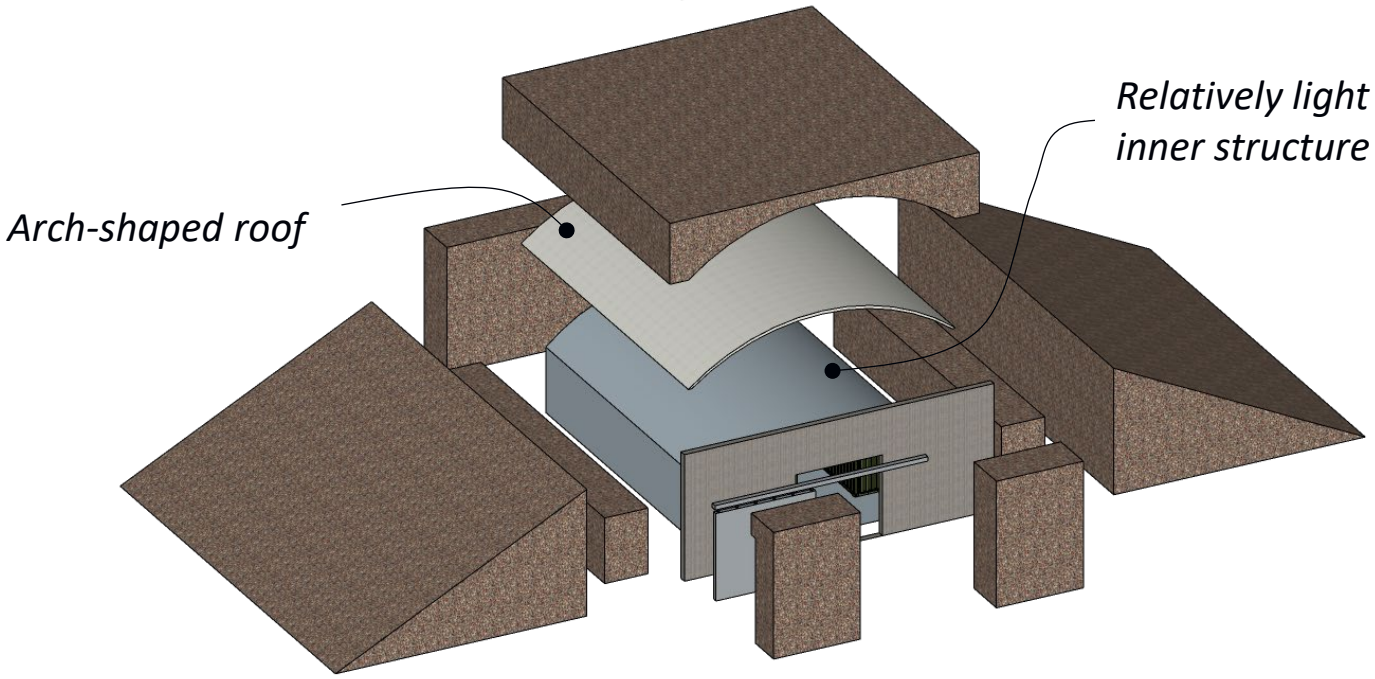
i) Expected resistance (ES performance):

- Increased earth mass with reinforced soil components
- Extended earth cover at the front for added protection
- Arch-shaped roof for higher load-bearing capacity

ii) Expected effects (PES performance):

- Less hazardous debris
  - Reduced concrete use
  - Increased earth-based debris
- Enhanced energy absorption through additional earth coverage





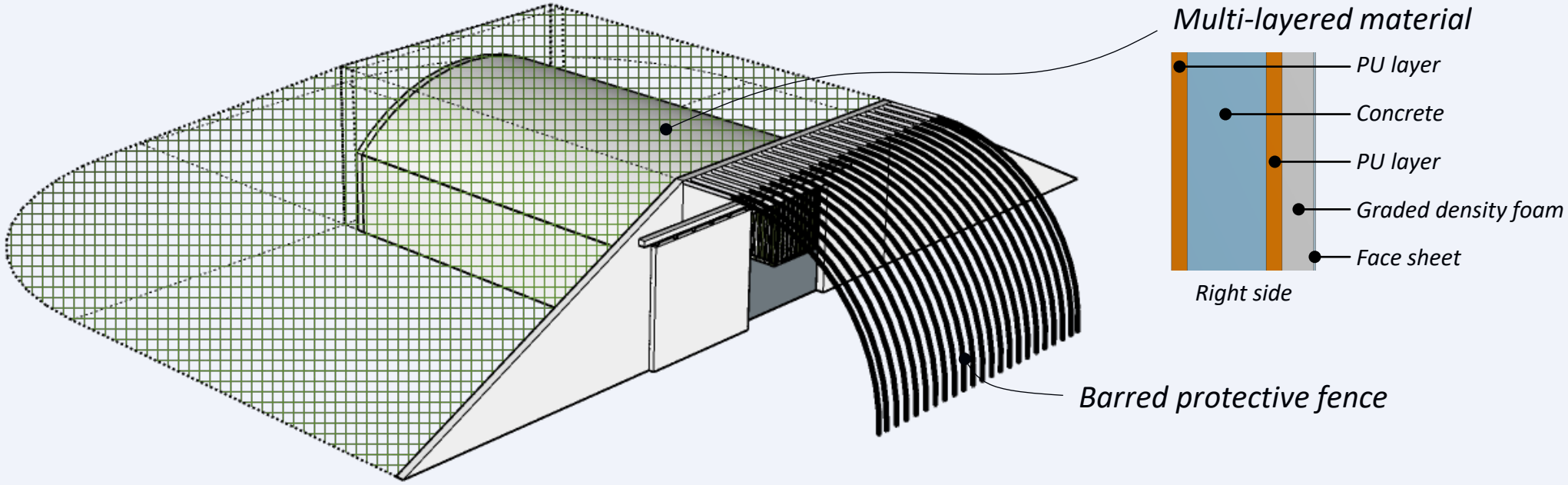
Design 2: Multi -layered magazine

i) Expected resistance (ES performance):

- Multi-layer walls utilizing material advantages
- Arch-shaped geometry for load distribution
- Optional barred fence to diffract blast waves

ii) Expected effects (PES performance):

- Reduced hazardous debris (less concrete)
- PU layer and earth cover help contain debris



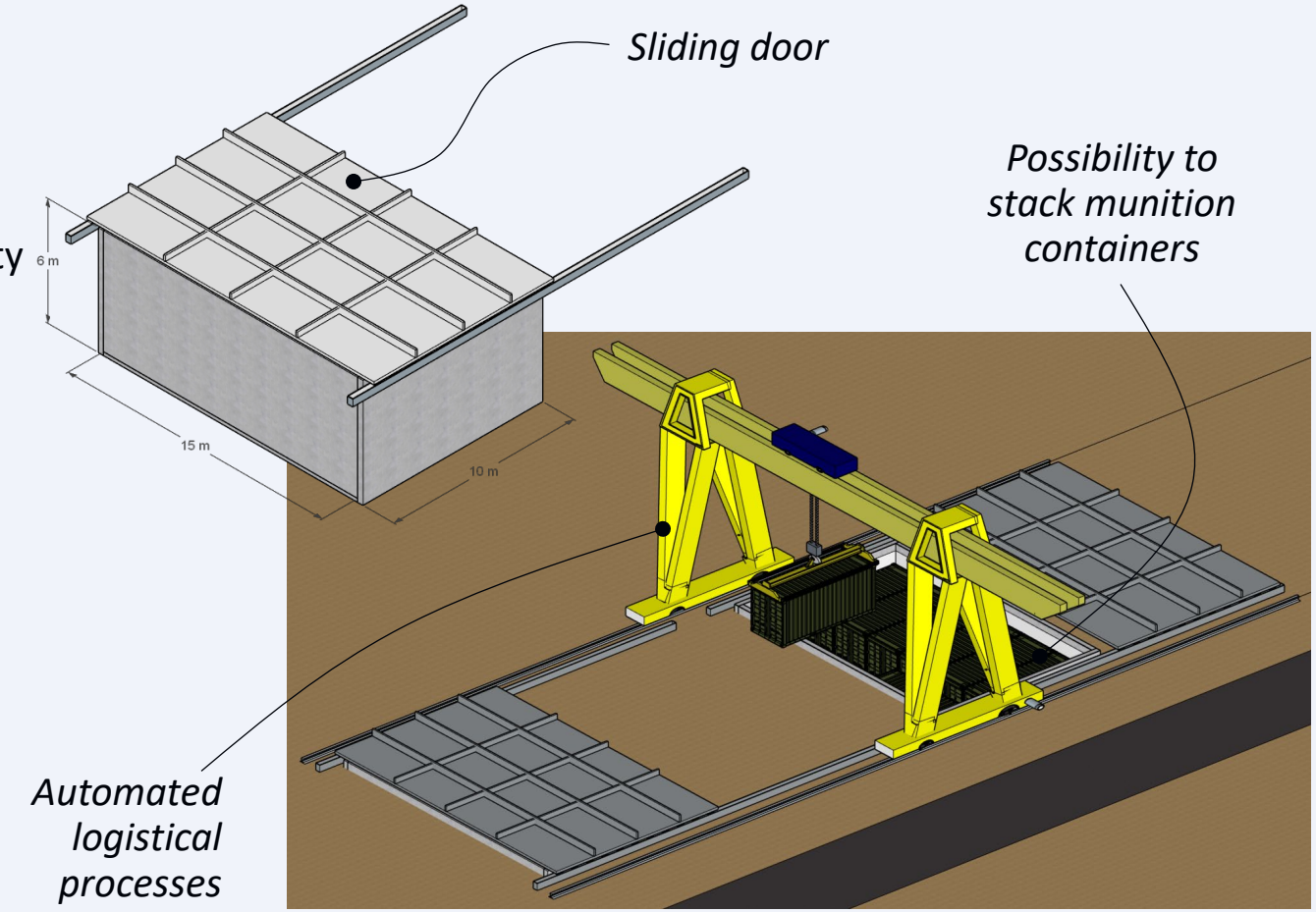
Design 3: Underground storage

i) Expected Resistance (ES Performance)

- Embedded in earth for maximized protection
- Mechanically stabilized earth for structural integrity
- Single vulnerable side (top)

ii) Expected Effects (PES Performance)

- Earth absorbs blast energy and captures debris
- Blast load and debris redirected upward



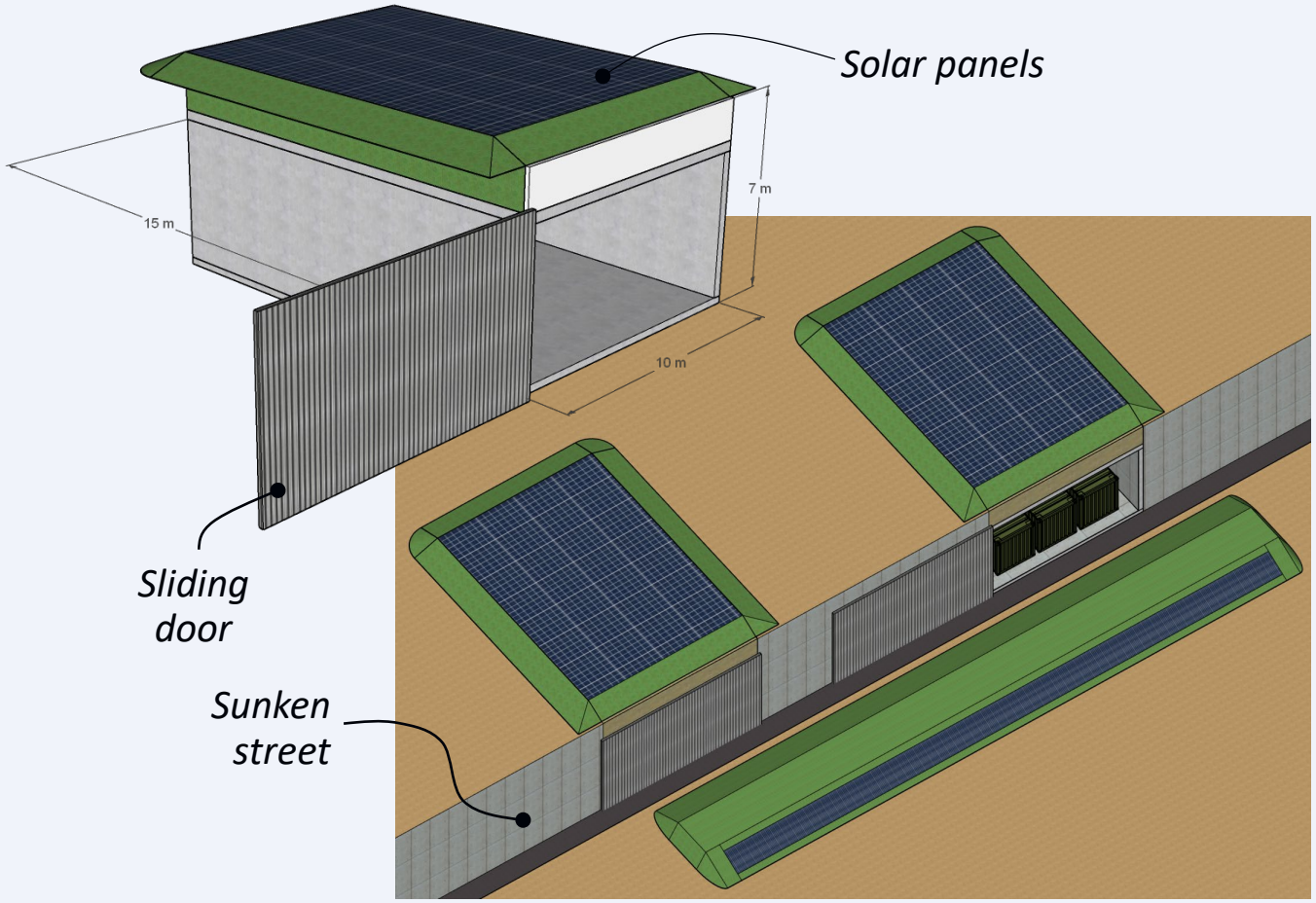
Design 4: Sunken street storage

i) Expected Resistance (ES Performance)

- Embedded in earth for maximized protection
- Heavier door to counter blast reflections in sunken street

ii) Expected Effects (PES Performance)

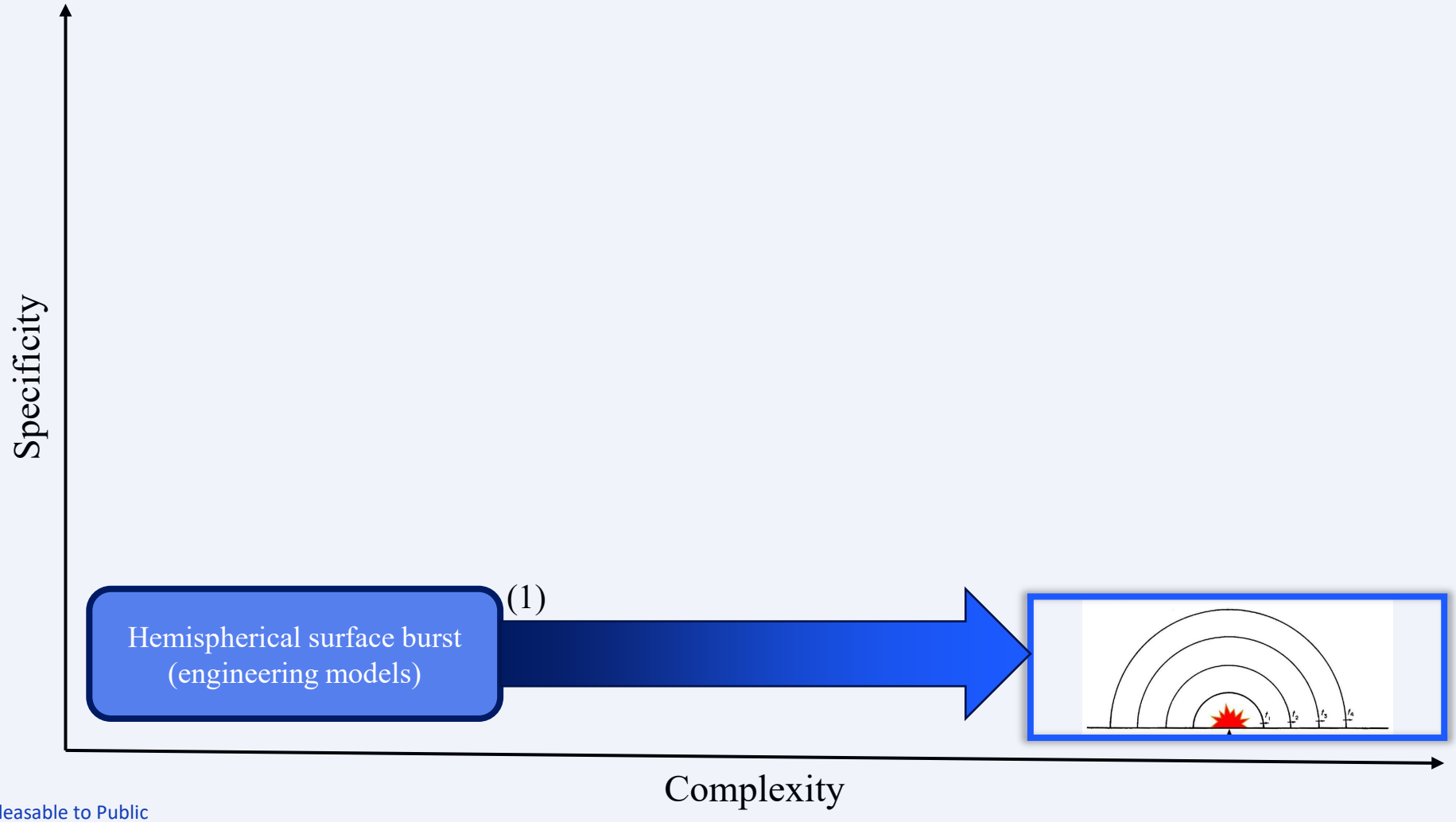
- Controlled blast exit via roof or door
- Sunken street acts as natural barricade for debris
- Directional blast mitigation with repurposed soil for added protection



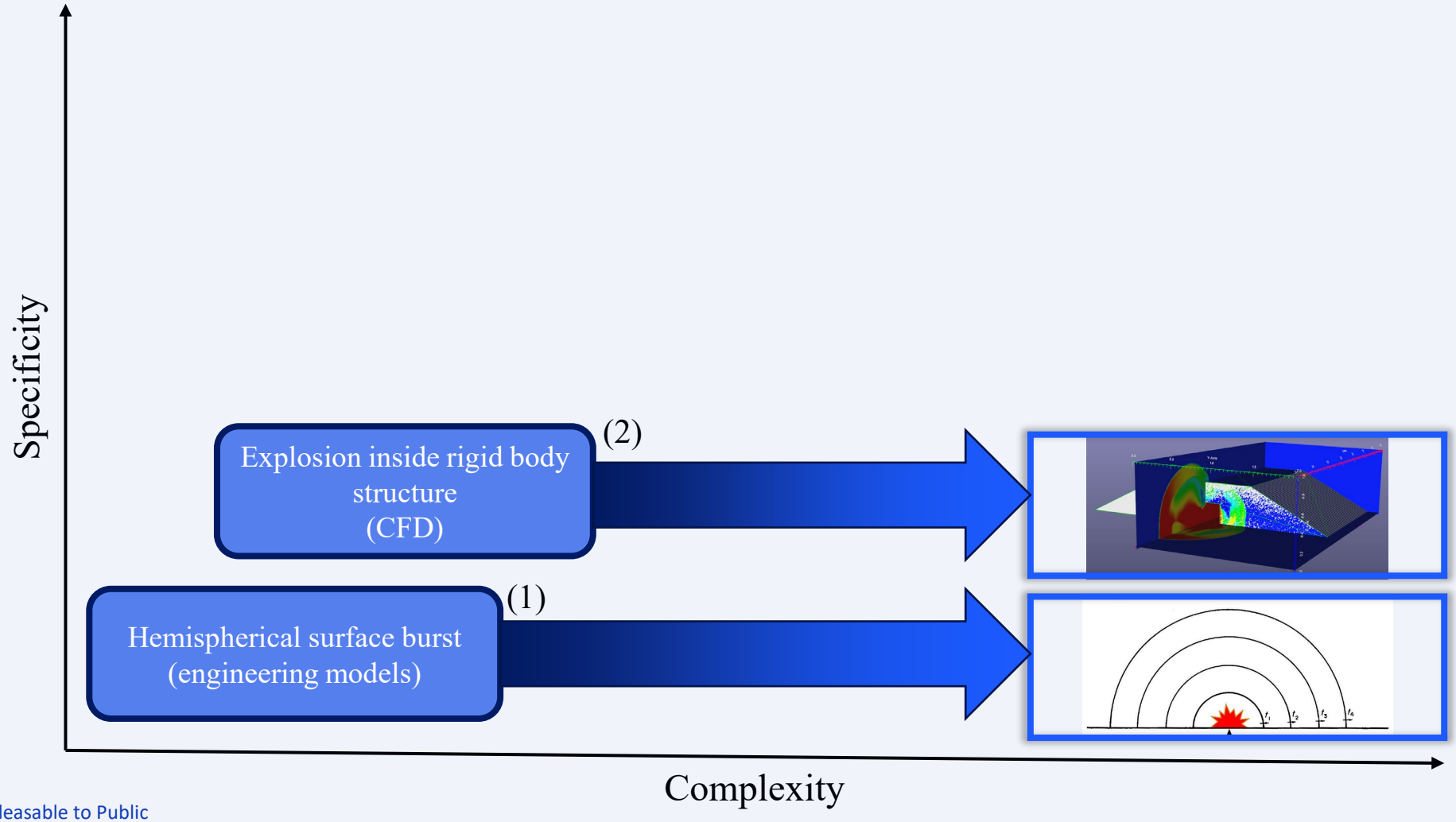
2. Performance modelling - approach

- Presented magazine designs aim to minimize interior and exterior safety distances
- Effectiveness still under assessment, focusing on:
  - *Outgoing* blast intensity and projected debris from PES
  - Structural resilience against *incoming* explosion effects and debris at ES
- Currently CFD simulations (Viper::Blast) to predict blast effects
  - Inform safety distances
  - Stepwise methodology balancing complexity and accuracy
  - Initial simulations on conventional ECMs for validation

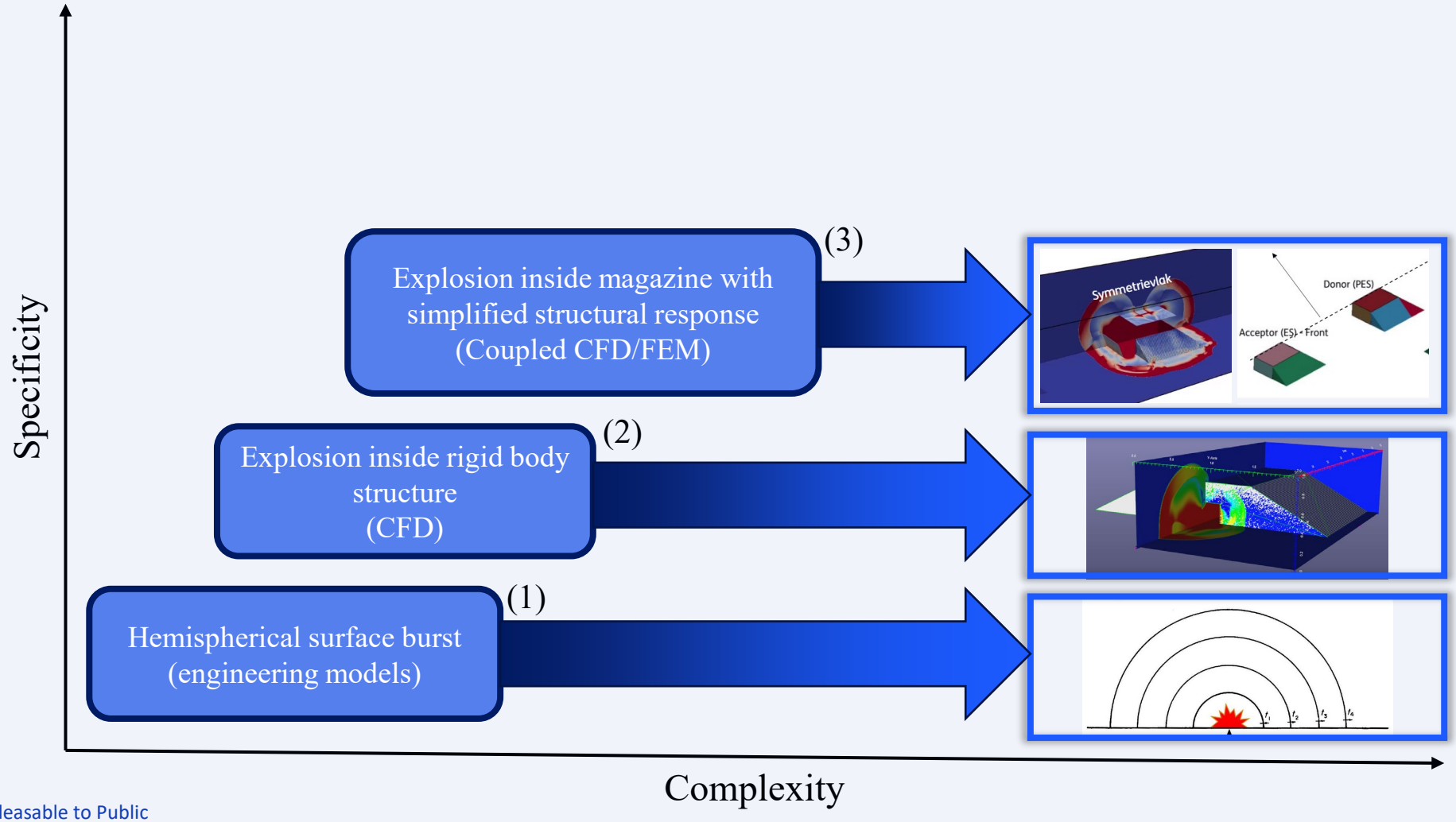
2. Performance modelling - approach



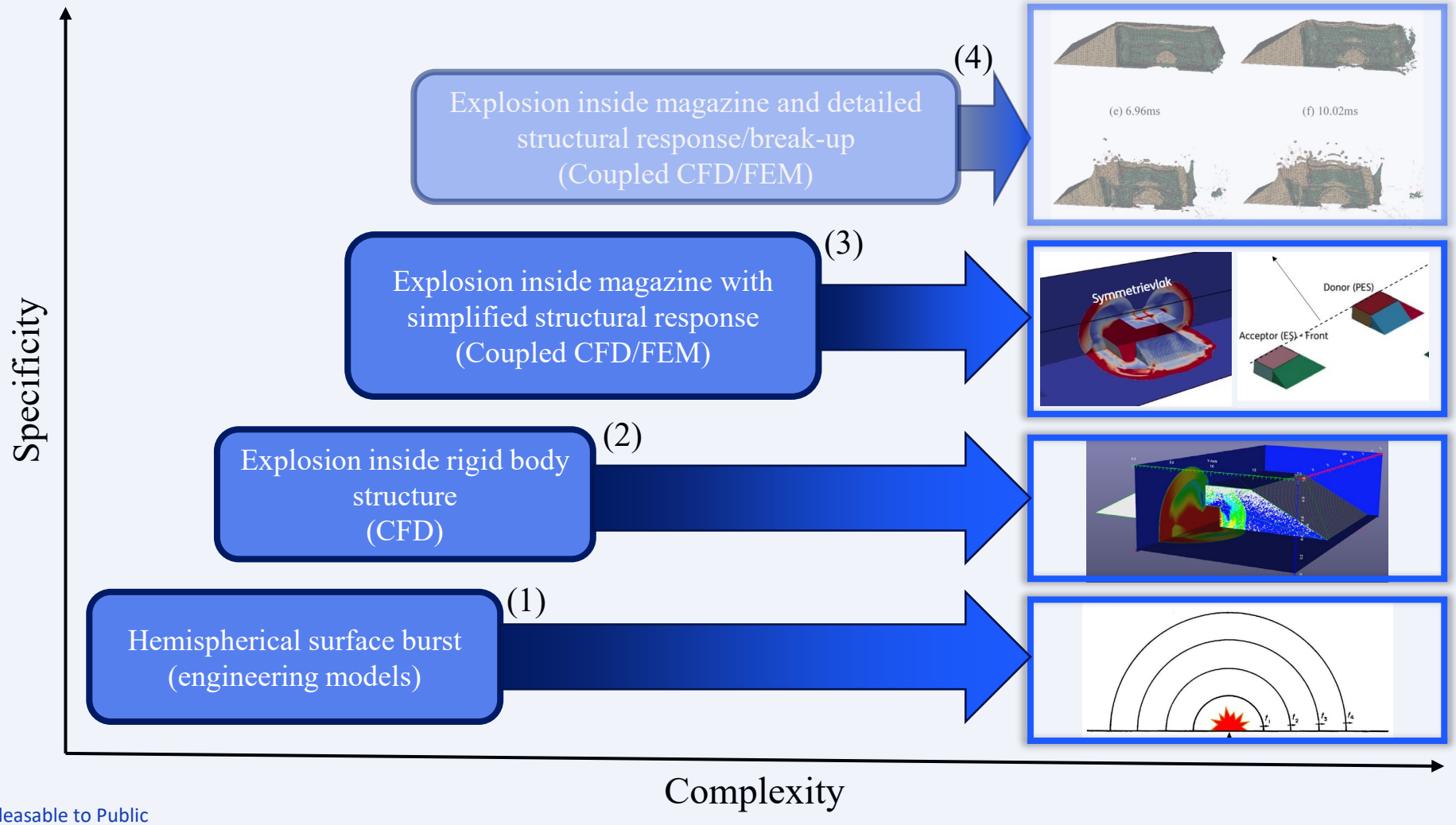
2. Performance modelling - approach



2. Performance modelling - approach



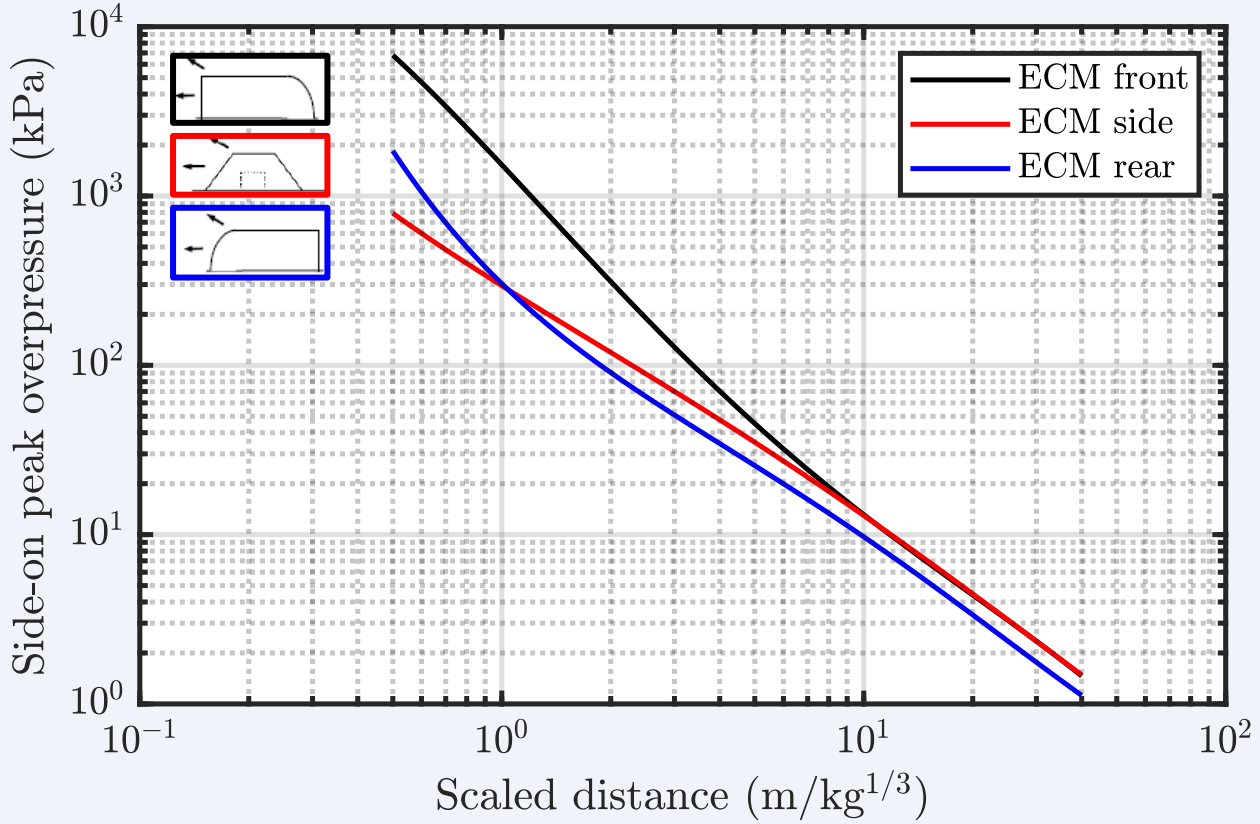
2. Performance modelling - approach



2. Performance modelling - output

CFD simulation output:

- Predict blast effects (pressure and impulse at PES)
- Generate effect-distance curves for:
  - NEQ limits & safety distances
    - IMD, IBD, etc.



2. Performance modelling - output

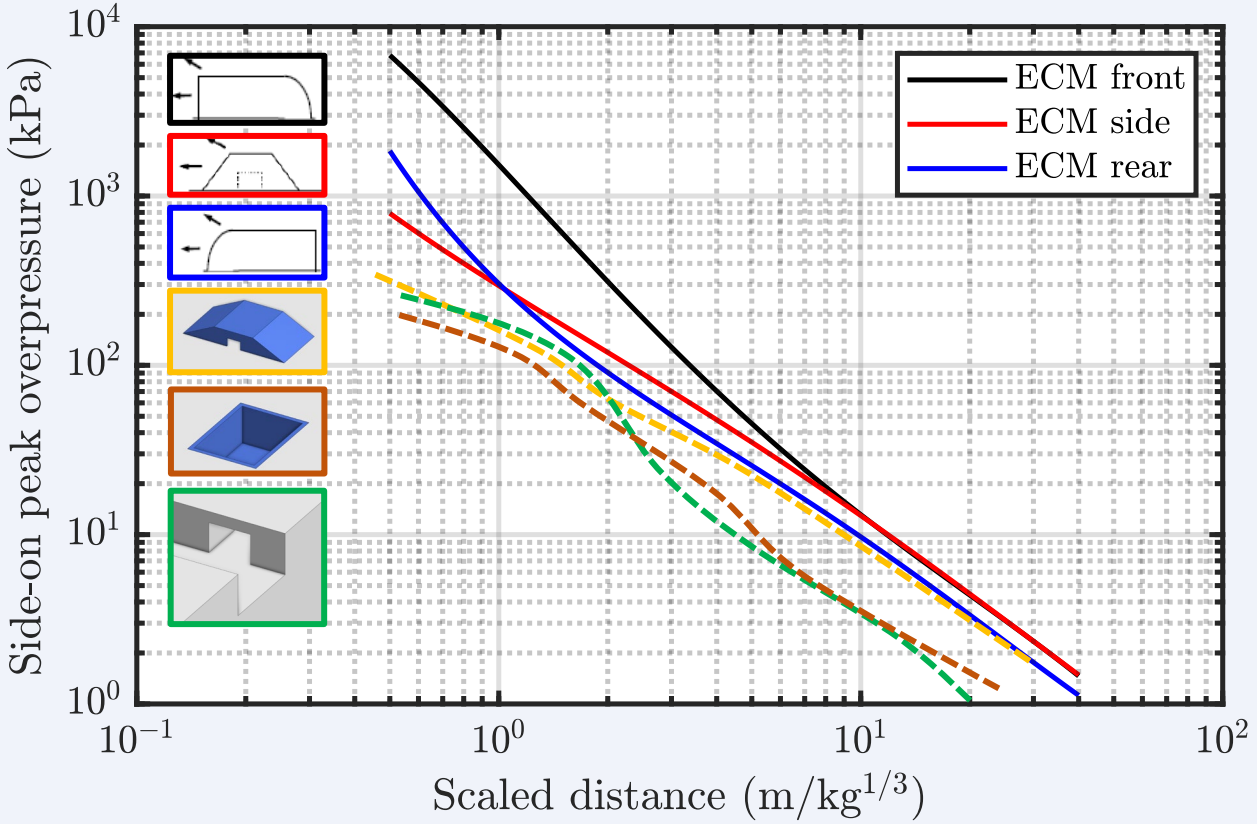
CFD simulation output:

- Predict blast effects (pressure and impulse at PES)
- Generate effect-distance curves for:
  - NEQ limits & safety distances
    - IMD, IBD, etc.

Performance evaluation:

- Comparing blast effects across magazine types
- Combine simulation results with empirical data from conventional ECMs (AASTP-4)

** Shown curves are illustrative only*



3. Depot integration

- Magazines are part of a larger Munition Storage Depot
- Depots can serve multiple purposes, e.g.:
  - Long-term stockpiling
  - Rapidly deployable capacity
  - Integrated with bases or training grounds
- Each depot type has unique requirements
- Depot integration is analyzed based on:
  - Key Performance Indicators (KPIs)
  - Optimization approach

3a. Depot integration - KPIs

Key Performance Indicators (KPIs):

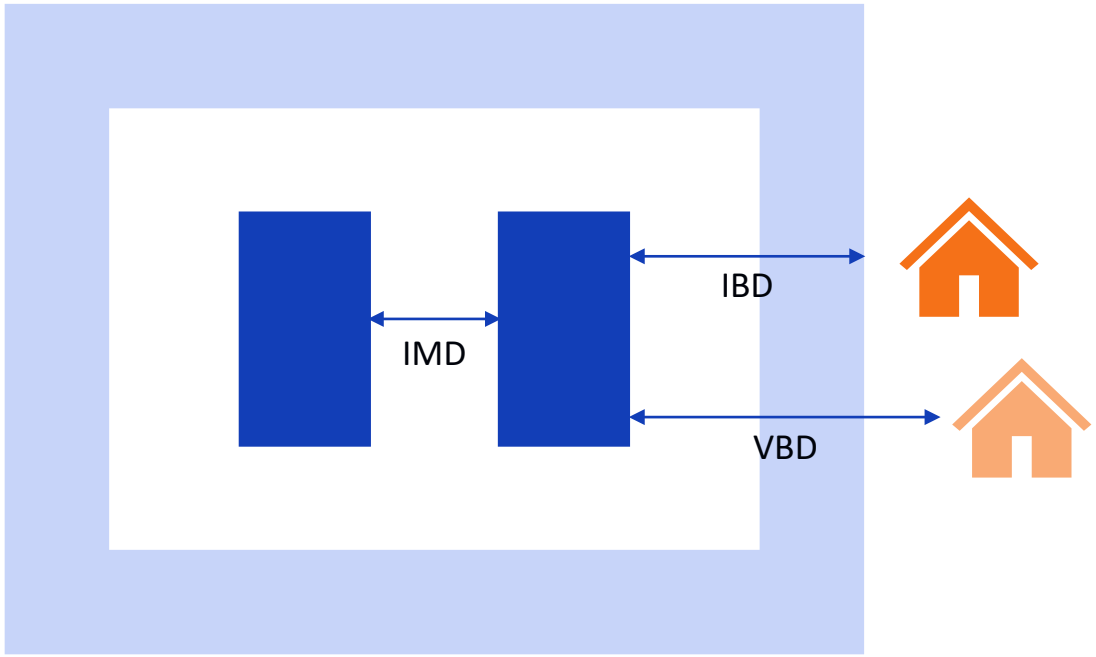
- Drafted in collaboration with the Dutch MoD
- Quantify and differentiate depot characteristics and operational needs
- Depend on depot type and priorities
  - Example: Stockpiling vs. Rapidly deployable capacity

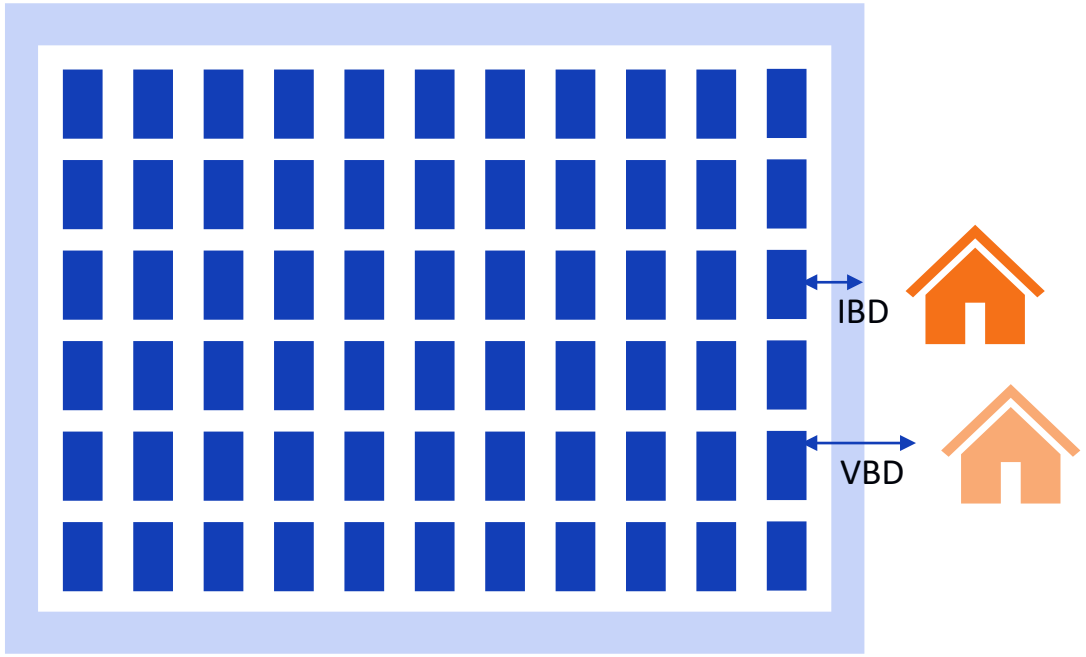
KPI	Description	Quantity (units)
Safety distances	Interior and exterior safety distances determine the spatial footprint and magazine layout	IMD, IBD (m)
Storage capacity	The storage capacity per surface area is an indicator for storage efficiency	NEQ/surface area (kg/m^2)
Logistical performance	Storage depots can aim for various logistical performances, which can be magazine inherent	NEQ/day (kg/day) $t_{magazine\ (un)loading}$ (s)
Costs	Relevant costs for munition storage realization	EUR/USD
Energy security	Storage depots require large amounts of energy which can be supplied by its own generation (e.g. solar and wind power).	% of self sufficiency

3b. Depot integration - Optimization

Balancing KPIs for optimal munition storage depot design

- Trade-offs: higher storage capacity → larger safety distances

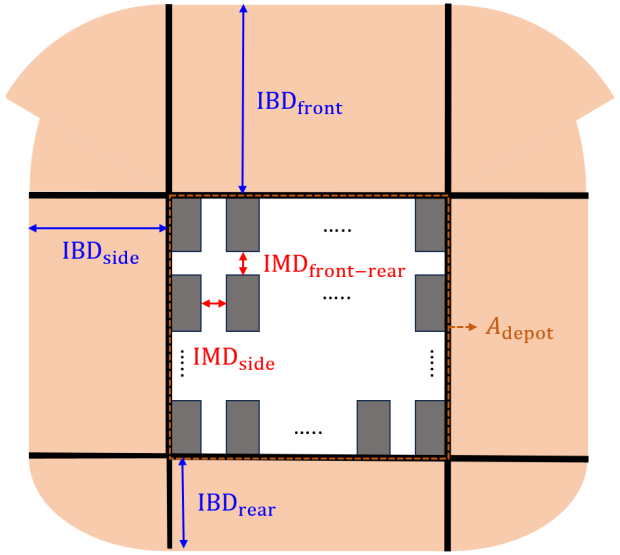


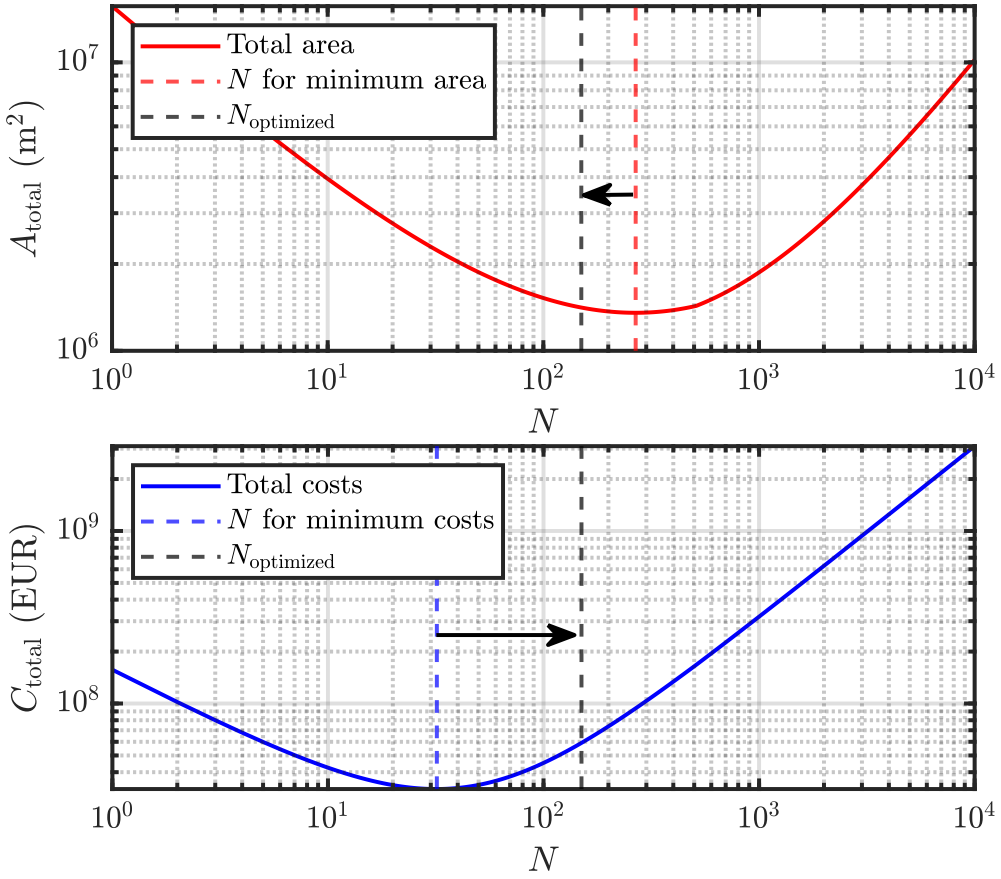


3b. Depot integration - Optimization

Example:

- Optimize for the number of magazines (N), considering:
  - Required depot storage capacity
  - Costs per land area
  - Magazine type
    - Dimensions
    - Construction costs
    - Safety distances (CFD)



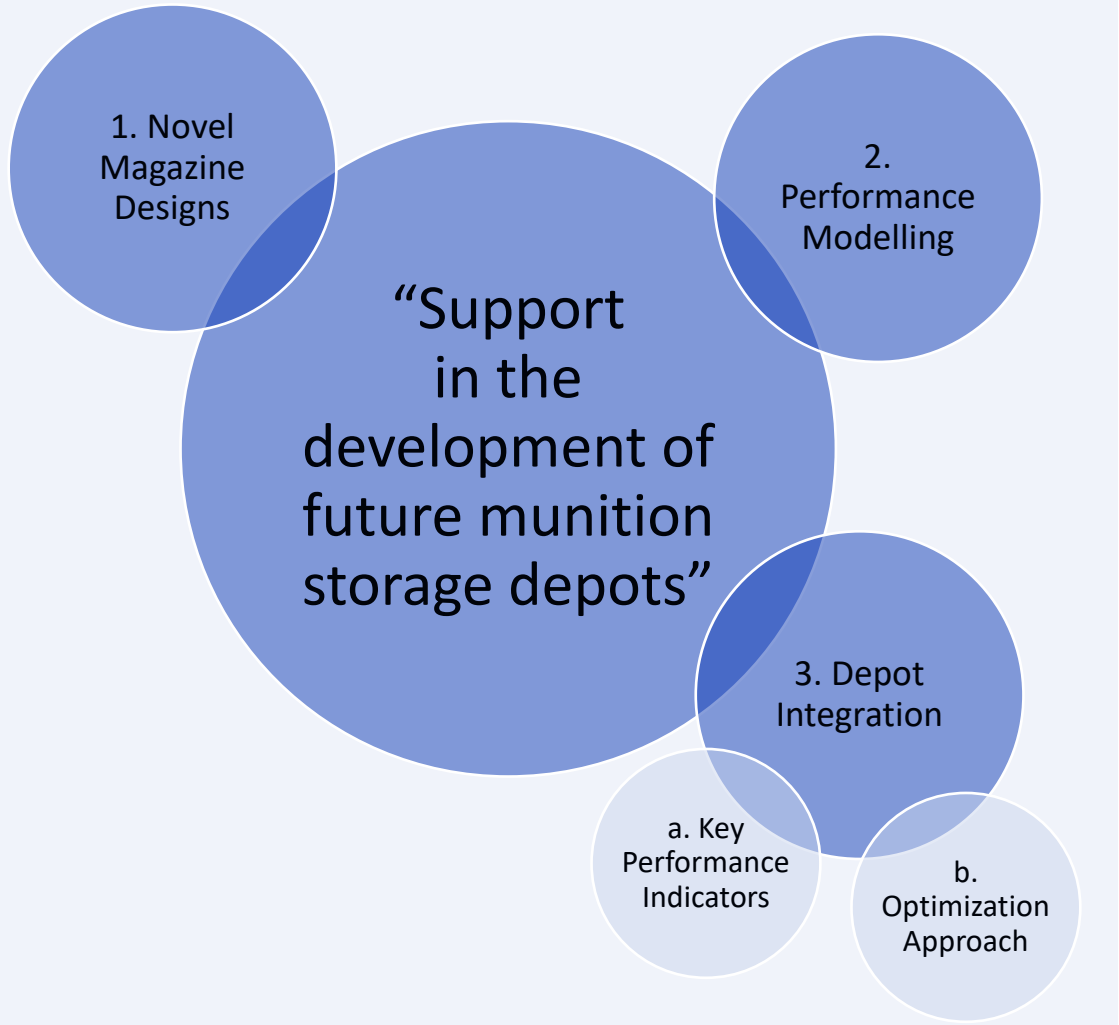


Conclusions

- Four innovative magazine concepts challenging conventional ECMs
- Modeling approach for verification (Outgoing blast effects with)
- KPIs enable structured evaluation and optimization
- Ongoing research, call for international feedback

Future work

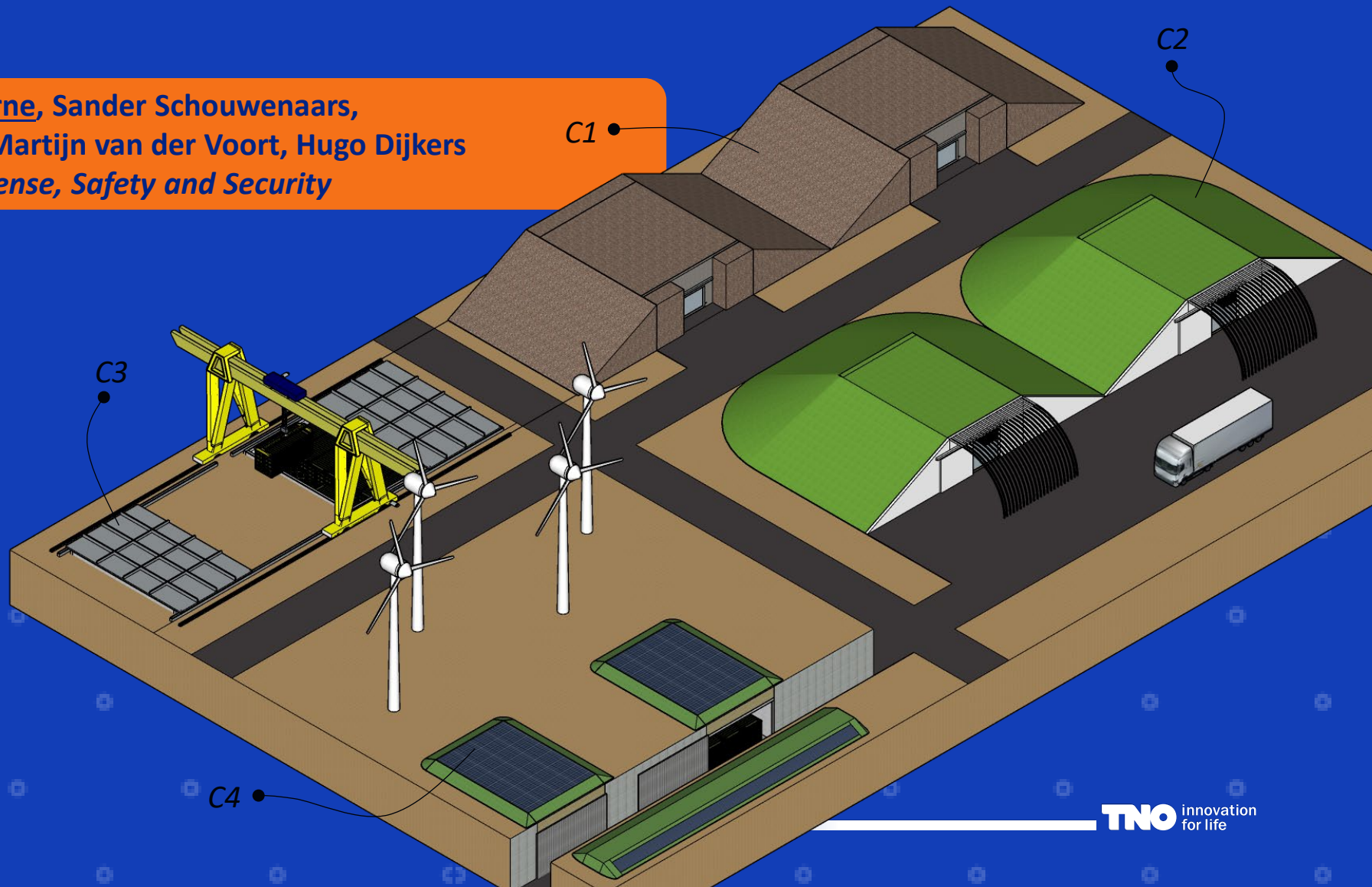
- Further assessment of magazine designs
- Expand KPIs with stakeholder input
- Optimize depot layouts for various KPIs



IESS 2026

Developments towards the munition storage depot of the future

Yinte Verberne, Sander Schouwenaars,
Dieter van der Pol, Martijn van der Voort, Hugo Dijkers
- TNO Defense, Safety and Security



TNO innovation for life