Webinar #6

From Risk Scenarios to Response Plans with Simulation Technologies

Italian Pilot - Execution part 1: Infrastructures Fire Emergency Management Strategy

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Antonio Retaggio
TECNOSISTEM SpA (third part STRESS)
aretaggio@tecnosistemspa.it

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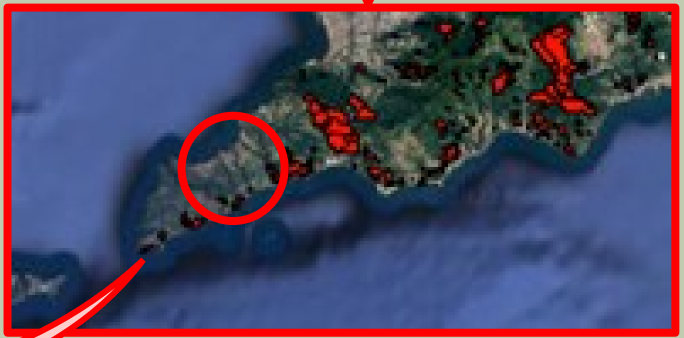
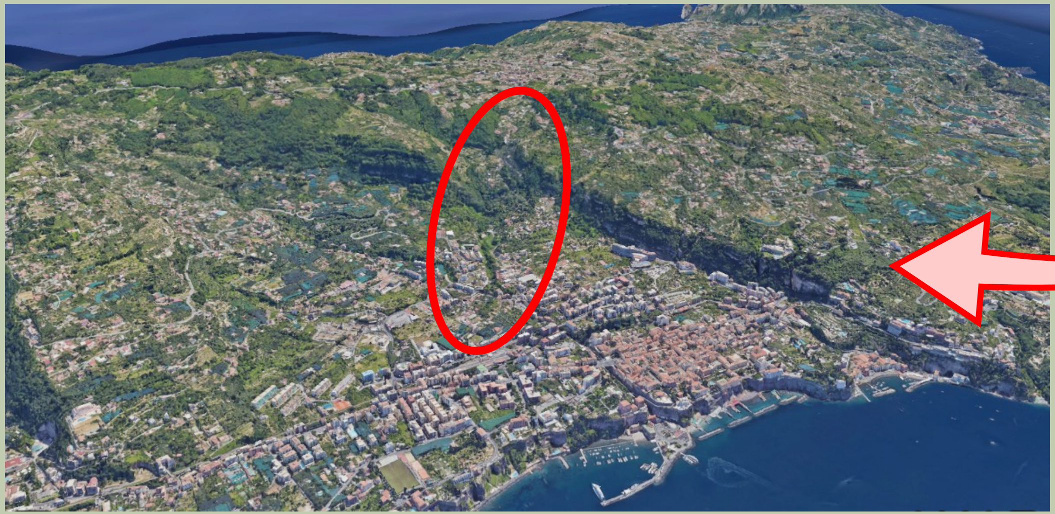
Italian Pilot – Sorrento Peninsula

The activities of the Italian Pilot are focused on the **Sorrento Peninsula**, a densely populated area with urban settlements and very dense wooded areas on the slopes, in Southern Italy.

The original pilot idea is inspired by the ongoing feasibility study for the construction of **a cable car system** to connect a sea level location to the ridge of the peninsula, integrating the regional rail transport system with connection to remote areas accessible only by car.





Italian Pilot – Execution part 1: Infrastructures Fire Emergency Management Strategy

The activities of the “Execution part 1 - Infrastructures Fire Emergency Management Strategy” are aimed at demonstrating the **integrability of the tools and technologies** developed in the Prevention and Preparedness Phase of the TREEADS project **within a typical transport infrastructure design process**.

A particular attention was given to the **safety topics**, as well as the **evaluation of the risk factors** for passengers, the definition of **innovative mitigation measures or safety systems** and emergency procedure for transport infrastructure in case of a wildfire.

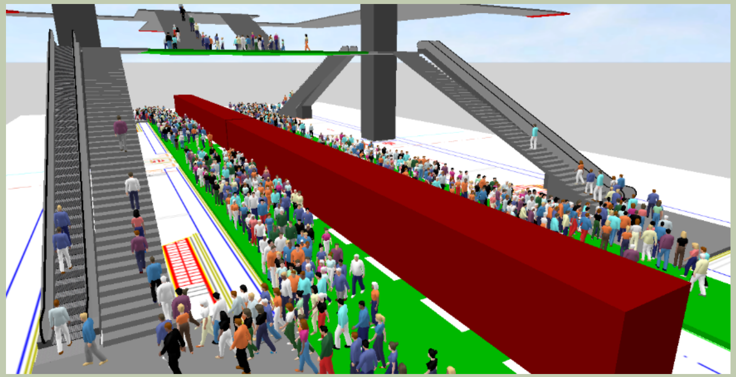
- IT–5 – Simulation of forest fires in the Sorrento Peninsula
- IT–6 – Optimization of cable car layout
- IT–7 – Analysis of temperature field on structural parts and main systems of cable car
- IT–8 – Analysis of smoke and toxic species diffusion on cable car
- IT–9 – Analysis of passenger evacuation, evaluation of liveability parameters during fire emergency
- IT–10 – Evaluation of innovative mitigation measures and safety systems
- IT–11 – Guideline development for the overall Infrastructures Fire Emergency Management Strategy

Infrastructures Fire Emergency Management Strategy

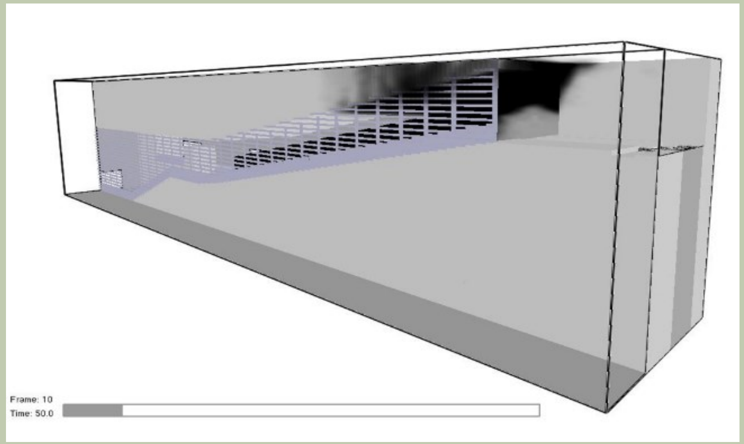
The results of the **Forest Fire Spread Simulation (IT-5)** performed by USAL have been used to generate the set of inputs needed for the **CFD 3D analyses** of smoke and toxic species diffusion, coupled with the **pedestrian evacuation simulations (IT-9)** .

These simulations are aimed at defining an **optimized layout (IT-6)** of the cable car route, as well as **the effects of fire (IT-7)** on the infrastructure and the **risk factors (IT-8,9)** for passengers in terms of residual visibility and toxic species concentration.

This approach verifies the effectiveness of **innovative systems and emergency procedures (IT-10)** across a large spectrum of non-standard scenarios, also not limited to the pilot itself.



Example of pedestrian evacuation analysis (VISWALK)



Example of smoke diffusion analysis on a train in a funicular station (FDS)

Infrastructures Fire Emergency Management Strategy

IT–5 Simulation of forest fires in the Sorrento Peninsula

As first step, an extensive simulation campaign has been set with the **Forest Fire Spread Simulation tool**, developed by the **University of Salamanca** (USAL).

16 different ignition points have been considered, selected among those deemed most critical in terms of potential environmental effects and impacts on the planned infrastructure, under varying prevailing wind conditions.

Figure 1: Fire ignition point locations on the ortophoto of the pilot area.

Table 2: Location of suggested fire ignition points

Ignition point	Lon (°E)	Lat (°N)
1	14.378274	40.611028
2	14.373858	40.609746
3	14.376233	40.608543
4	14.384481	40.608328
5	14.387707	40.612476
6	14.382459	40.612768
7	14.377944	40.615748
8	14.378791	40.619017
9	14.374669	40.618268
10	14.369874	40.621231
11	14.393101	40.606891
12	14.389452	40.607257
13	14.393552	40.602040
14	14.394574	40.600703
15	14.395123	40.598731
16	14.398385	40.597002

Infrastructures Fire Emergency Management Strategy

IT–5 Simulation of forest fires in the Sorrento Peninsula

Table 3: Summary of burning and burned area after 4hr of wildfire simulation in phyFire

Simulation ID	Fire ignition point	Wind speed (km/h)	Wind direction (º)	Burning area (ha)	Burned area (ha)
IP_NE14_f05	5	13.7	NE / 45	5.7	6.57
IP_NE14_f06	6	13.7	NW / 315	7.69	9.61
IP_NW14_f07	7	13.7	NW / 315	0.19	0.2
IP_NW14_f08	8	13.7	NW / 315	77.01	191.65
IP_NW14_f09	9	13.7	NW / 315	23.07	38.1
IP_NW14_f10	10	13.7	NW / 315	26.76	50.85
IP_SE14_f12	12	13.7	SE / 135	9.56	15.37
IP_SWW14_f01	1	13.7	SWW / 220	0.41	0.46
IP_SWW14_f02	2	13.7	SWW / 220	3.67	4.06
IP_SWW14_f03	3	13.7	SWW / 220	0	0
IP_SWW14_f04	4	13.7	SWW / 220	0.29	0.33
IP_SWW14_f05	5	13.7	SWW / 220	2.44	2.79
IP_SWW14_f06	6	13.7	SWW / 220	7.84	10.4
IP_SWW14_f07	7	13.7	SWW / 220	2.97	3.41
IP_SWW14_f08	8	13.7	SWW / 220	90.69	159.25
IP_SWW14_f09	9	13.7	SWW / 220	118.06	221.23
IP_SWW14_f10	10	13.7	SWW / 220	9.97	12.67
IP_SWW14_f11	11	13.7	SWW / 220	1.65	1.7
IP_SWW14_f12	12	13.7	SWW / 220	2.51	2.56
IP_SWW14_f13	13	13.7	SWW / 220	1.26	1.45
IP_SWW14_f14	14	13.7	SWW / 220	3.74	5.65
IP_SWW14_f15	15	13.7	SWW / 220	5.68	11.84
IP_SWW14_f16	16	13.7	SWW / 220	5.74	11.73
IP_SWW20_f01	1	20.1	SWW / 220	15.34	19.22

Table 3: Summary of burning and burned area after 4hr of wildfire simulation in phyFire

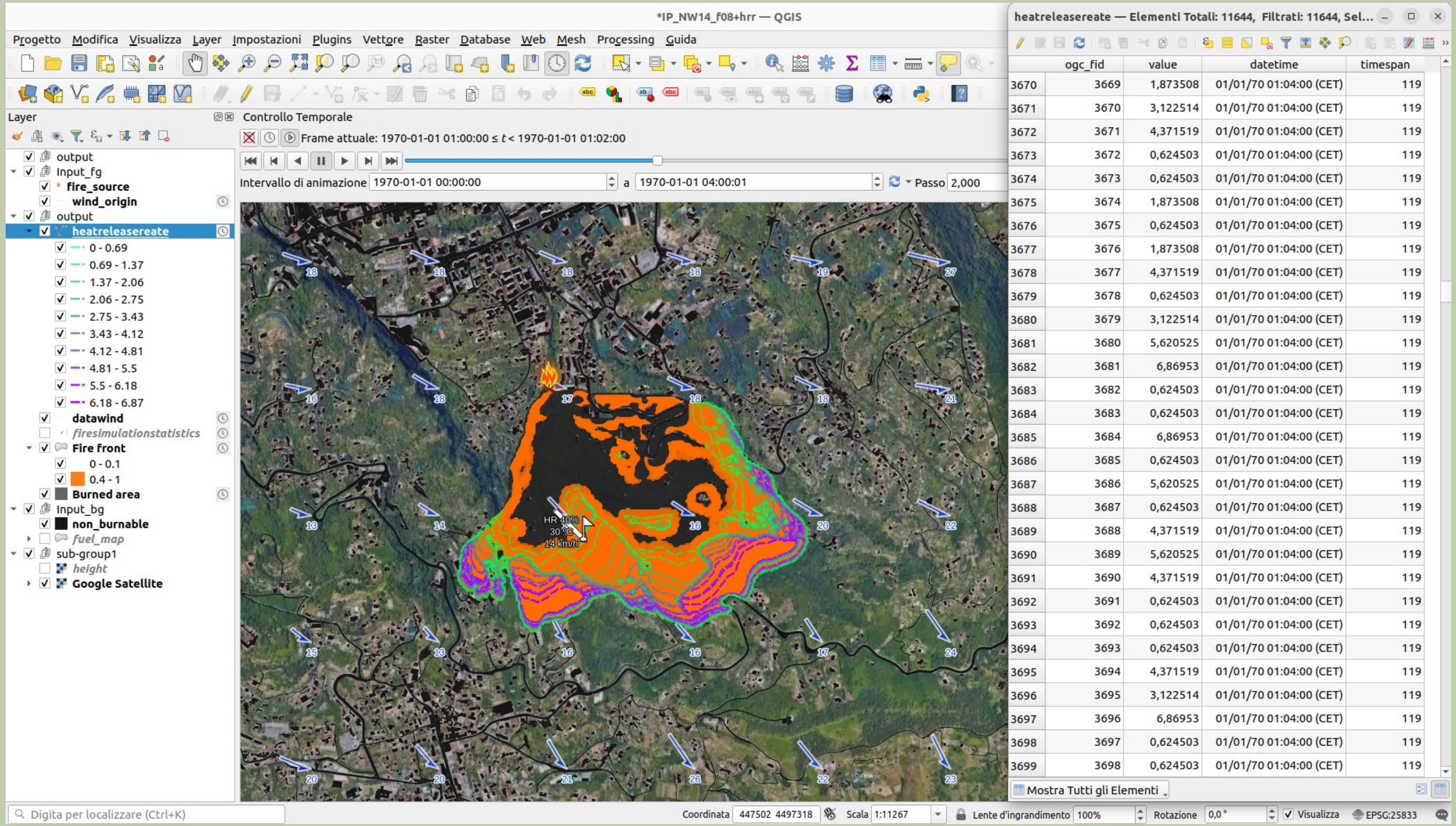
Simulation ID	Fire ignition point	Wind speed (km/h)	Burning area (ha)	Burned area (ha)
IP_f01_wb01	1	13.7	0.41	0.46
IP_f02_wb01	2	13.7	3.67	4.06
IP_f03_wb01	3	13.7	0	0
IP_f04_wb01	4	13.7	0.29	0.33
IP_f05_wb01	5	13.7	2.44	2.79
IP_f06_wb01	6	13.7	7.84	10.4
IP_f07_wb01	7	13.7	2.97	3.41
IP_f08_wb01	8	13.7	90.69	159.25
IP_f09_wb01	9	13.7	118.06	221.23
IP_f10_wb01	10	13.7	9.97	12.67
IP_f11_wb01	11	13.7	1.65	1.7
IP_f12_wb01	12	13.7	2.51	2.56
IP_f13_wb01	13	13.7	1.26	1.45
IP_f14_wb01	14	13.7	3.74	5.65
IP_f15_wb01	15	13.7	5.68	11.84
IP_f16_wb01	16	13.7	5.74	11.73
IP_f01_wb02	1	20.1	15.34	19.22

Infrastructures Fire Emergency Management Strategy

IT–5 Simulation of forest fires in the Sorrento Peninsula

The analysis of the evolution of burned areas and the corresponding **heat release** over time made it possible to identify the most critical scenario for the safety of the cable car.

This scenario was then used to define the input parameters for the computational fluid dynamics (CFD) solver generally used for safety design process of infrastructure.



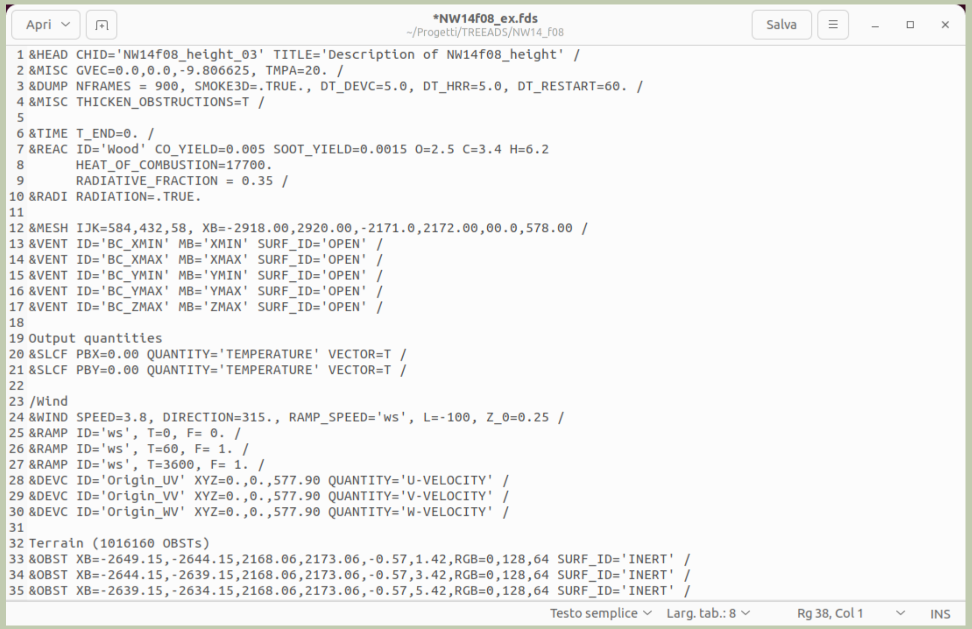
HRR MAPPING

Infrastructures Fire Emergency Management Strategy

IT–6 Optimization of cable car layout

The data transformation to obtain a readable format by the NIST/FDS (Fire Dynamic Simulator) software has been carried out using the Qgis application and the **Qgis2fds plugin**.

After importing the results of the first analysis into Qgis, the landuse and frontfire layers were transformed into rasters; detail and characteristics of the mesh grid were also set.



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      RADIATIVE_FRACTION = 0.35 /
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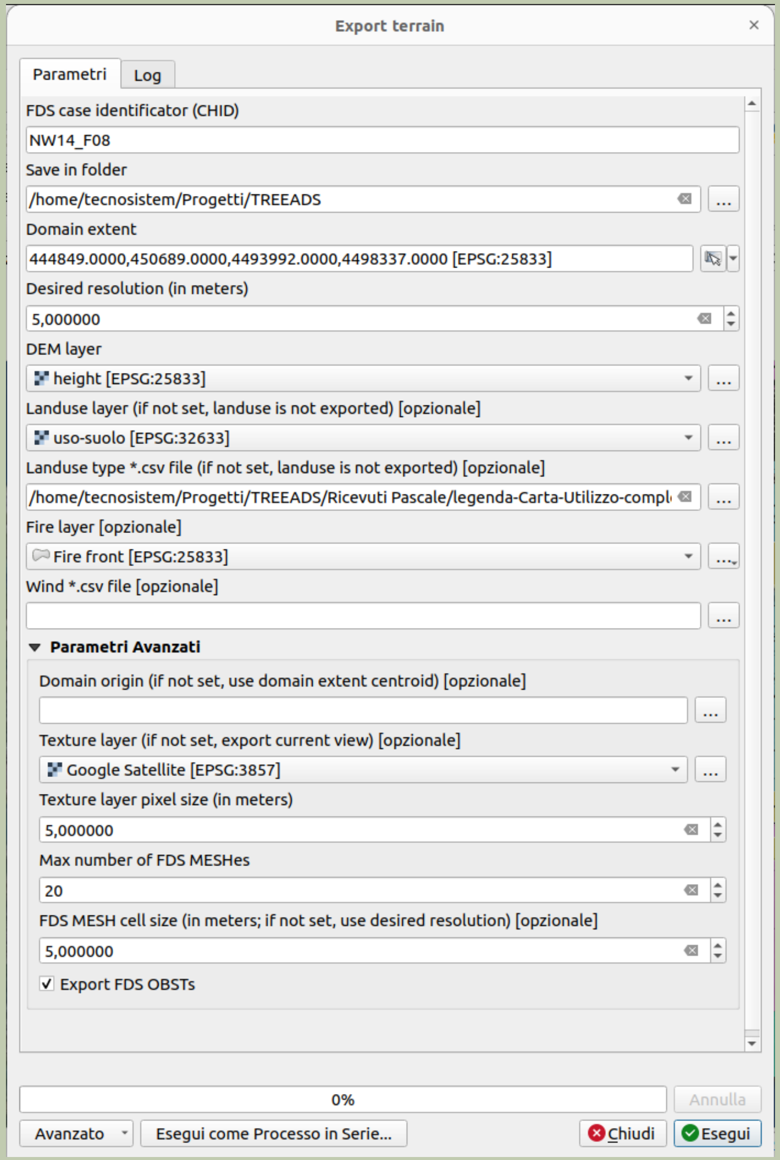
```

Temporary header of FDS input file – only for setting purpose ~ 1 million obstacles, ~ 15 million fluid cells



Qgis2FDS settings

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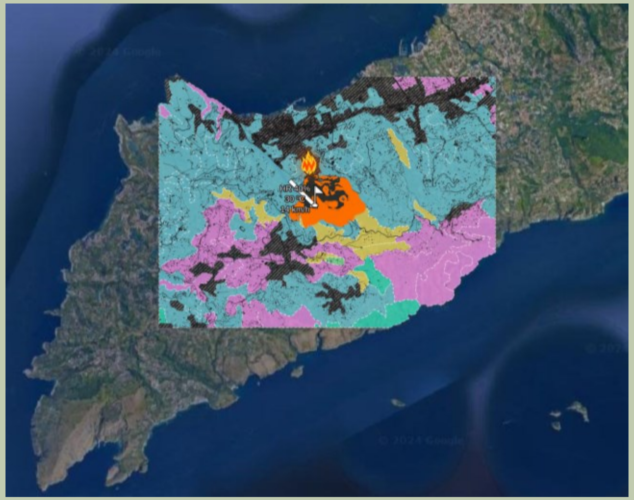
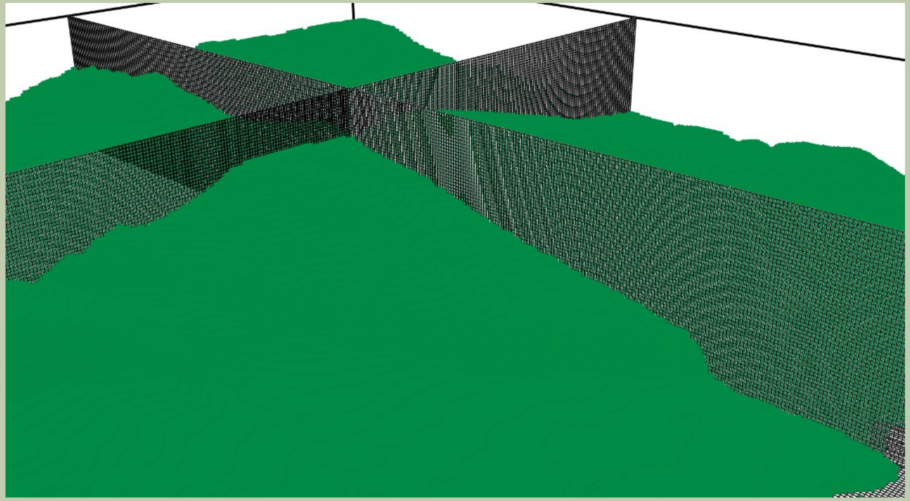
IT–6 Optimization of cable car layout

The next step involves the transformation of the flame spread data in order to obtain a value of the HRR Curve (Heat Release Rate) as a function of time for each point of the combustion area as the fire spreads.

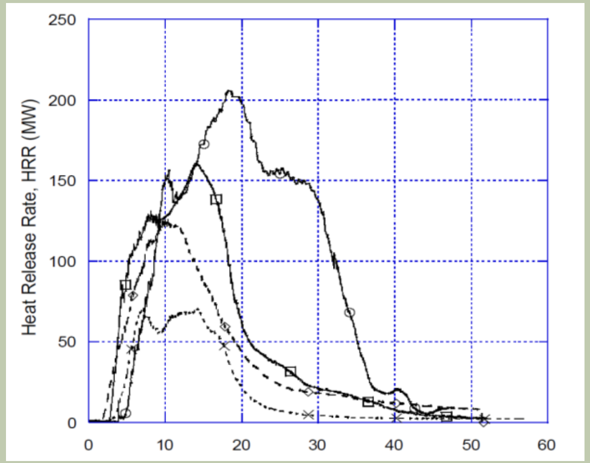


Forest Fire spread simulation (QGIS)

FDS general geometry model (Smokeview)



FDS fluid mesh detail (Smokeview)

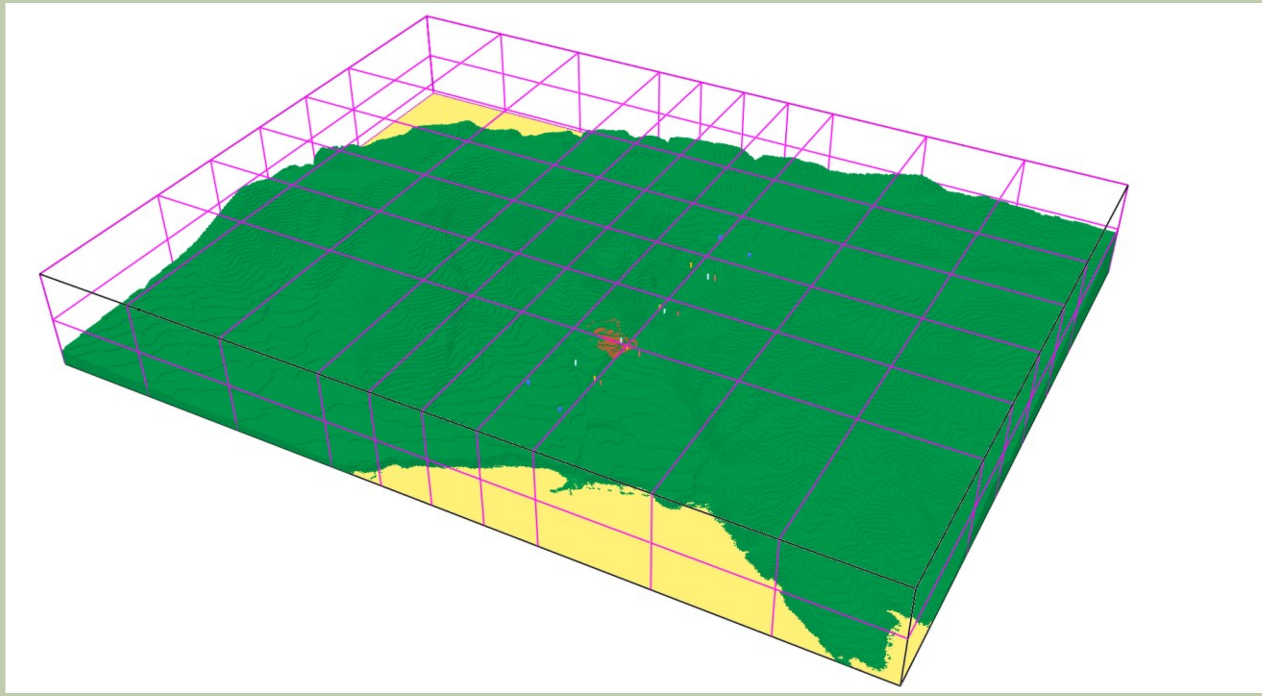


Example of experimental variable HRR Curve

Infrastructures Fire Emergency Management Strategy

IT–6 Optimization of cable car layout

The computational domain was divided into 64 basic meshes in order to divide the calculation across multiple processors. Following a set of sensitivity analyses, a further 56 refined meshes were provided to obtain adequate detail in the areas closest to the ignition area.



Computational domain – 120 meshes subdivision

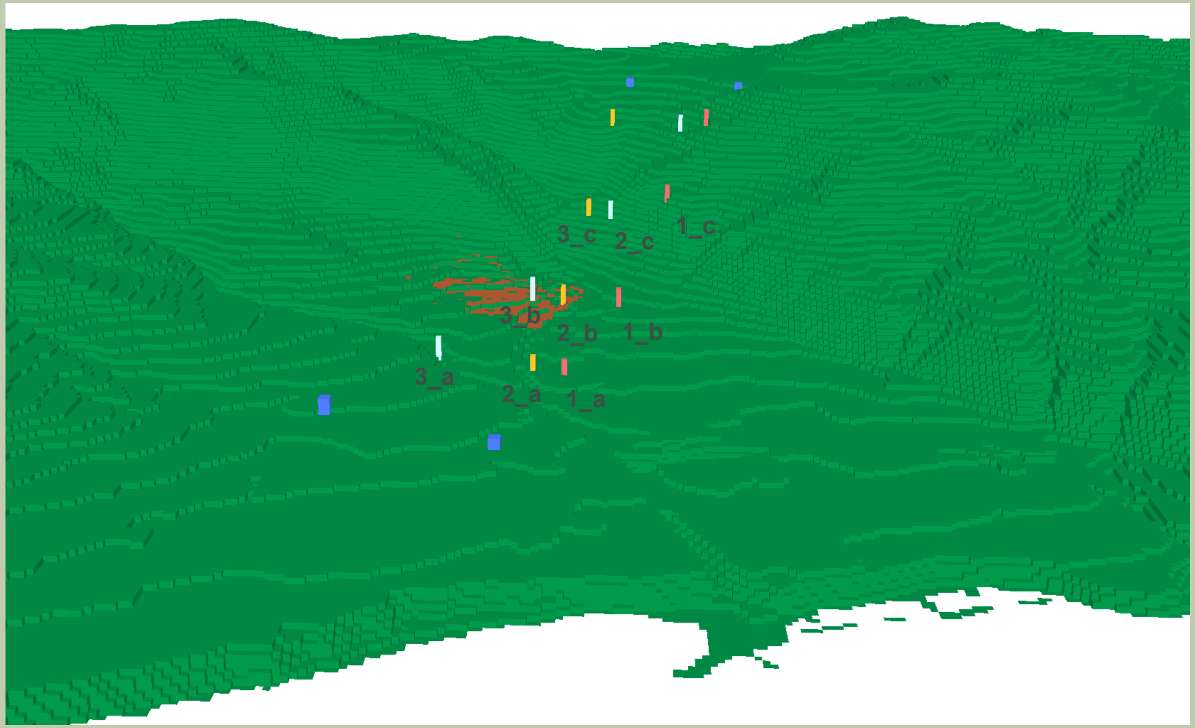
A model of ~ **36 million cells** was obtained, divided into **120 meshes**, such as to perform an unsteady CFD combustion calculation (0.15 seconds time step, 2400 seconds total time), in approximately 3-4 days on a workstation with 64 processors and 270GB RAM.

The final FDS input file consists of ~250000 lines of code.

Infrastructures Fire Emergency Management Strategy

IT–6 Optimization of cable car layout

The next activity was the inclusion of the three cable car layout alternatives selected during the design phase into the FDS model.
The location data and dimensions of the head and valley stations, of the aerial lift pylons, were obtained from the project CAD drawings, through the Qgis plugin.



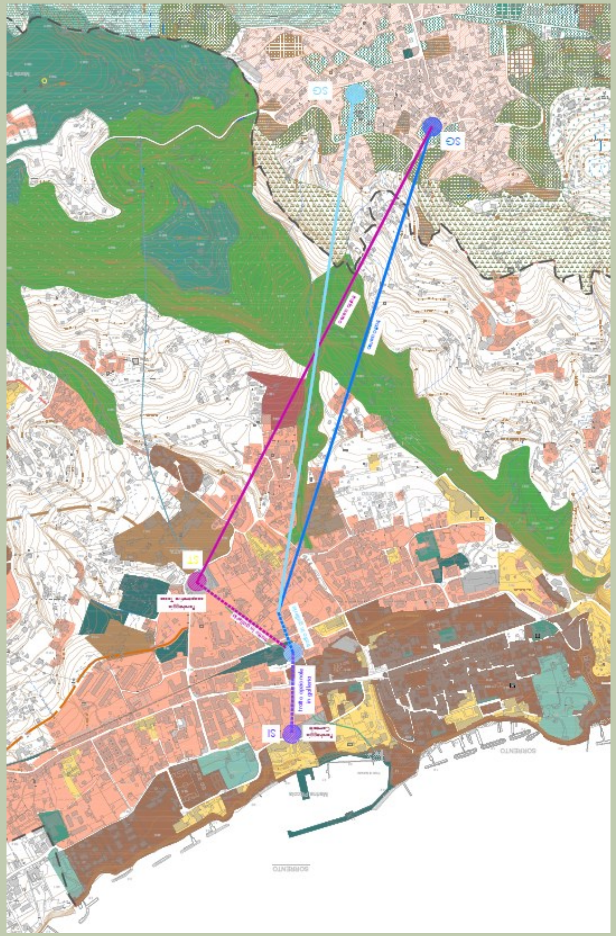
Head and valley stations, aerial lift pylons in FDS model

Stations

#1 alternative pylons

#2 alternative pylons

#3 alternative pylons



Three layout alternatives

Infrastructures Fire Emergency Management Strategy

IT–6 Optimization of cable car layout

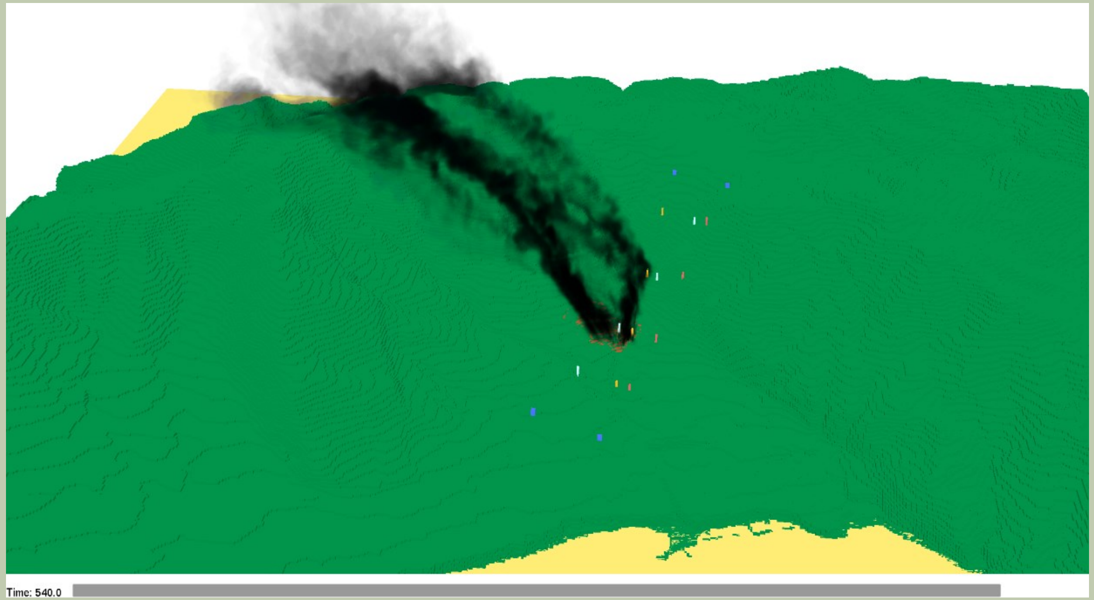
Example image

The next step was the development of the simulation campaign and post-processing.

The definition of the optimal cable car layout has been obtained through the analysis over time of the physical parameters considered in the international regulations for the safety of rolling stock: NFPA 130, ISO 13571:2012, NFPA 101, according to the criteria defined therein.

These main quantities are monitored at the base and top of the aerial lift pylons:

- **carbon monoxide** concentration
- soot **visibility**
- air **temperature**
- radiant **heat flux**
- accumulated **FED** (Fractional Effective Dose) for incapacitation



Test case – Smoke diffusion – 540 seconds

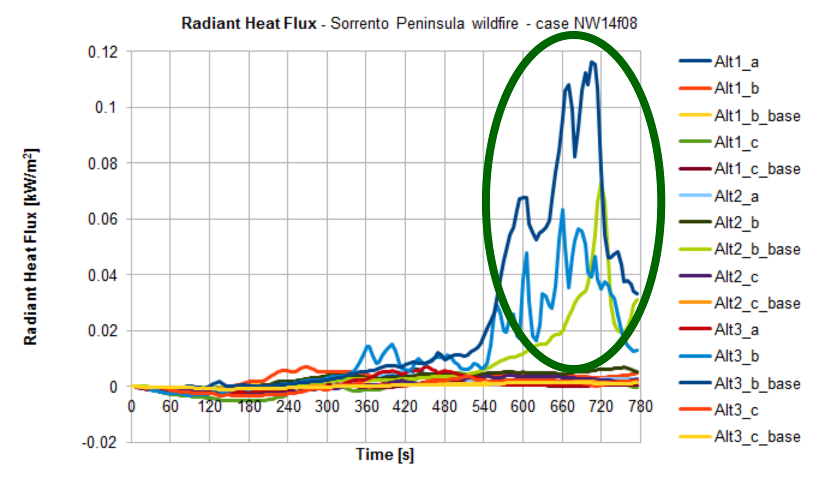
Infrastructures Fire Emergency Management Strategy
IT–6 Optimization of cable car layout

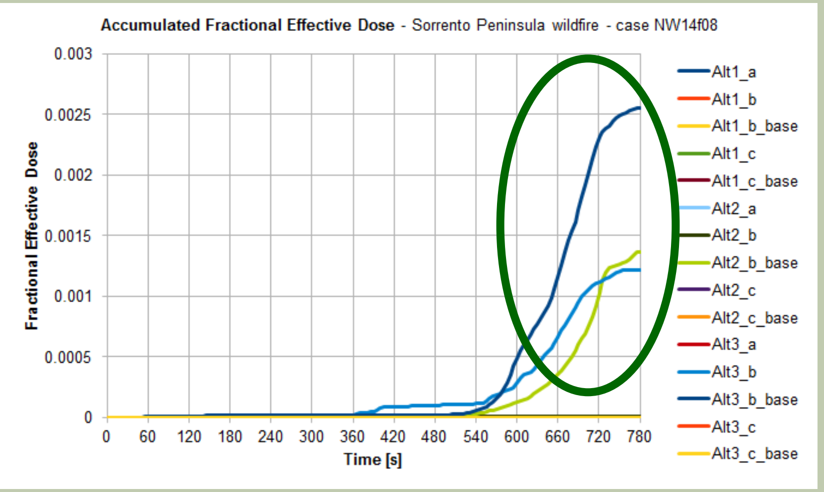
The evolution of physical quantities is shown up to 780 seconds, considering that **most of the safety procedures require that the self-rescue of the passengers occurs within 10 minutes** (600 seconds) from the beginning of detection of the fire.

Furthermore, from the analysis of the flow field it is evident that the areas that ignite after 10-12 minutes are located downstream of the different route alternatives and so do not affect the choice of the cable car layout, although the fire power continues to grow.

Analysing the graphs, a fairly uniform behaviour can be seen that allows to define immediately the **optimal cable car layout**.

For all the physical quantities involved, in fact, **unacceptable or potentially dangerous values** are detected on the **"b" pylons for the "2" and "3" route alternatives**, which instead remain almost unaltered for the "n.1" alternative.

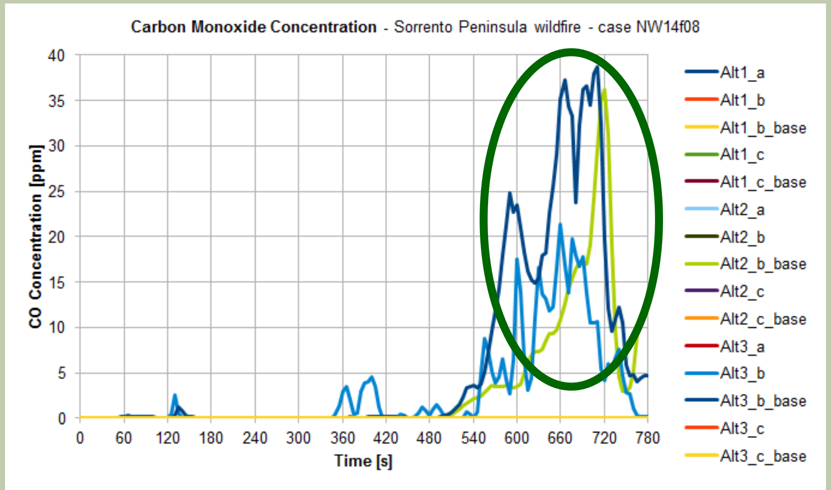


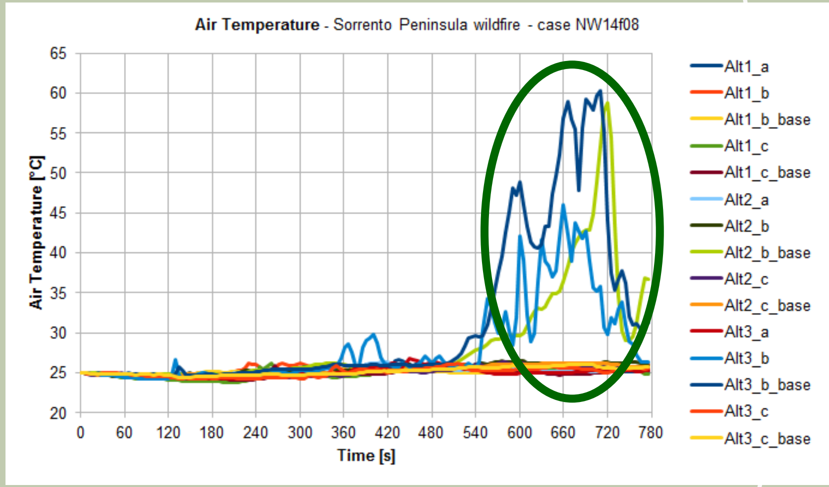


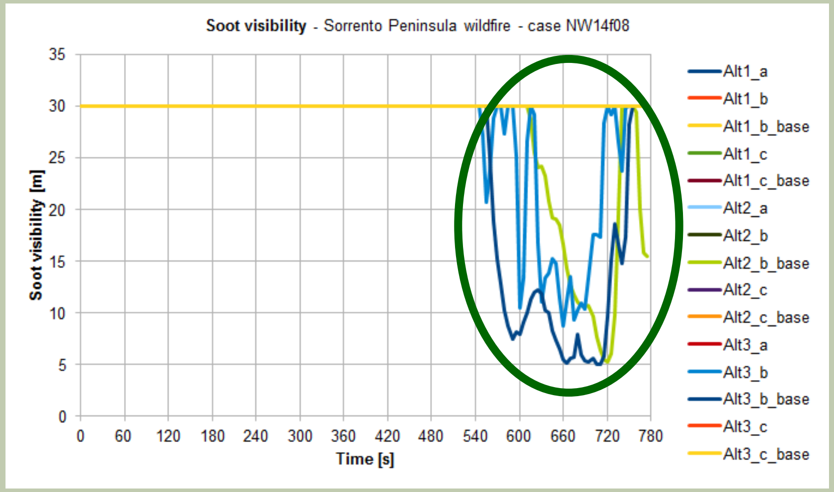
Infrastructures Fire Emergency Management Strategy
IT–6 Optimization of cable car layout

In particular, some **exceeding of the thresholds** imposed by the regulations (NFPA 130, ISO 13571, and national policy) can be noted for **residual visibility** and **inhaled air temperature**. **Carbon monoxide concentration** values are also worth mentioning.

It can also be noted that the most critical phase occurs between 540-570 seconds and 750-780 seconds of the fire simulation, in which the monitored pylons are located downstream of the burning areas, as previously mentioned.







Infrastructures Fire Emergency Management Strategy

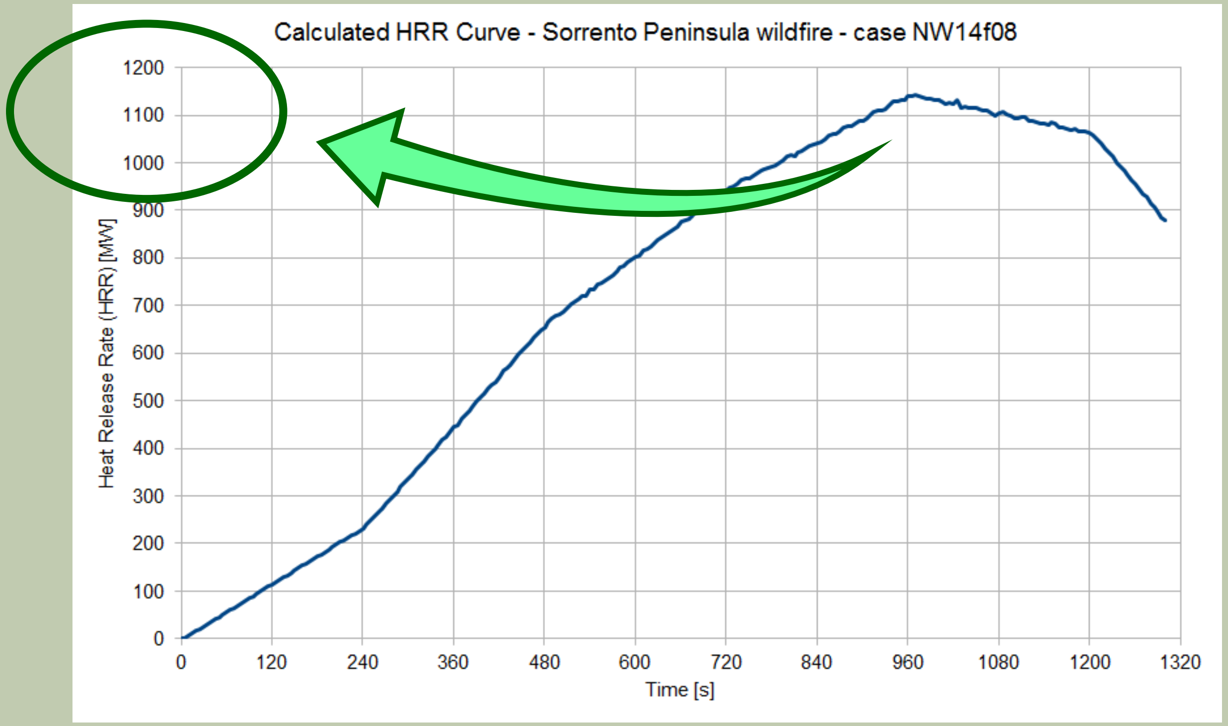
IT–6 Optimization of cable car layout

Another significant result is the **global HRR (Heat Release Rate) curve**, calculated as function of time for the entire ignition surface, obtained through the processing of the punctual data from the previous Forest Fire Spread Simulation.

This result is important to understand the typical powers to be expected in case of a wildfire.

Just as an example, typical **HRR peak value** for a subway fire ranging from **5 to 30 MW**, while in case of a fire in a road tunnel powers can range from **30 to 100 MW**.

The effect in terms of temperature and of toxic species concentration, however, is not comparable to these ratios, considering the **larger extension of the surfaces involved**, about 4, 5 hectares, ~400 times greater (and so lower density of heat released), and the **greater dilution** of the airborne substances emitted, due to the larger volumes involved and the atmospheric conditions.



*Calculated HRR Curve – **Only areas that ignite in the first 1200 seconds***

Infrastructures Fire Emergency Management Strategy

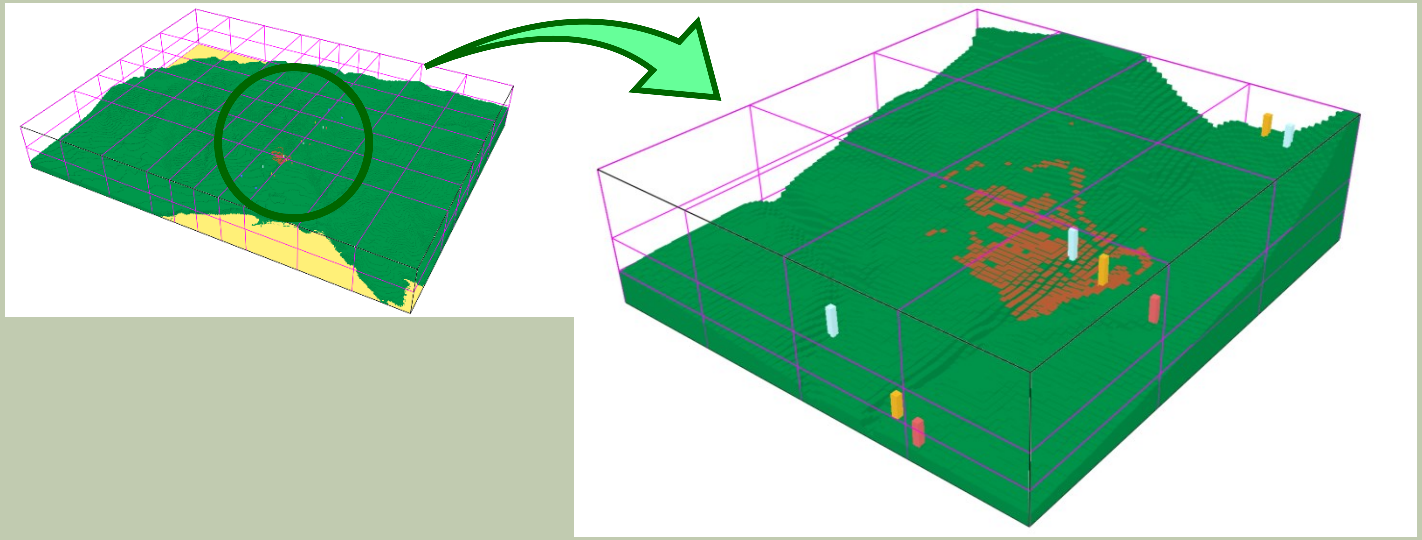
IT–7 Analysis of temperature field on structural parts and main systems of cable car

IT–8 Analysis of smoke and toxic species diffusion on cable car

The 3D CFD analysis aimed at defining the field values of temperature and the dispersion of toxic substances requires the generation of a model with a significantly **higher level of detail** compared to that used for defining the optimal layout, which only required a qualitative comparison between comparable solutions.

Following an extensive mesh sensitivity analysis campaign, a reduced-extent model was generated, focusing on the highest-risk areas, with a level of detail increasing from 5 m to 0.75 m.

This reduction was particularly necessary to accurately resolve the flame areas and, consequently, the radiated thermal power.



Computational domain comparison for IT-6 (left) and IT-7/8 activity (right)
Burning areas in brown

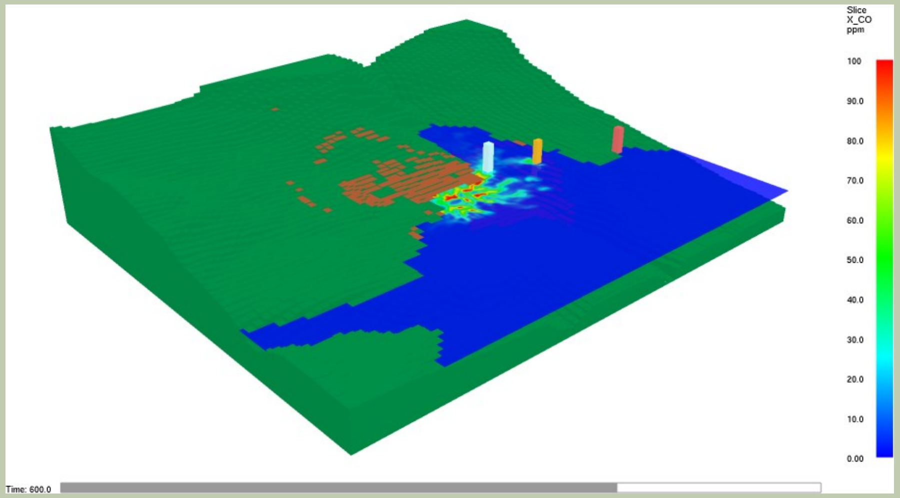
Infrastructures Fire Emergency Management Strategy

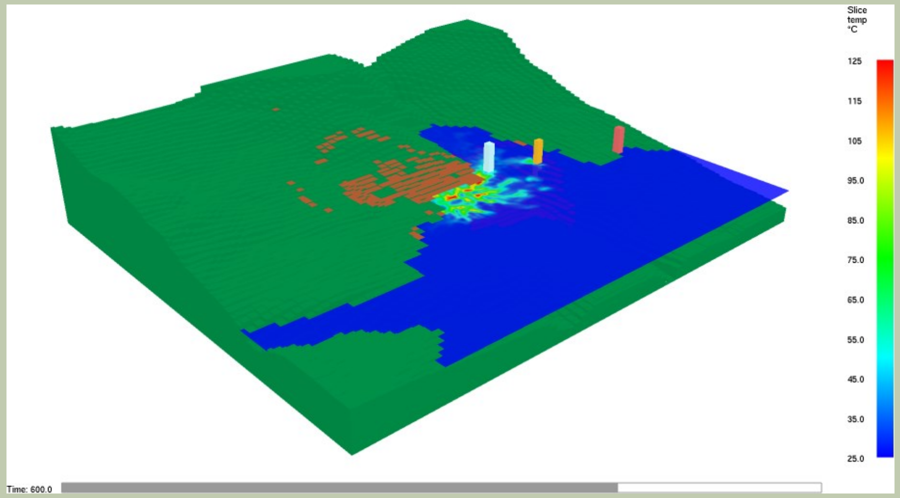
IT–7 Analysis of temperature field on structural parts and main systems of cable car

IT–8 Analysis of smoke and toxic species diffusion on cable car

The acceptance criteria and the monitored physical quantities are the same as in the previous case, as established by the aforementioned major international regulations.

However, it is necessary to **analyze the results over a significantly larger area** — one that encompasses all possible path positions of the transported cable car. The most effective approach for collecting results therefore appears to be the analysis of the contours of the main physical parameters at different heights.





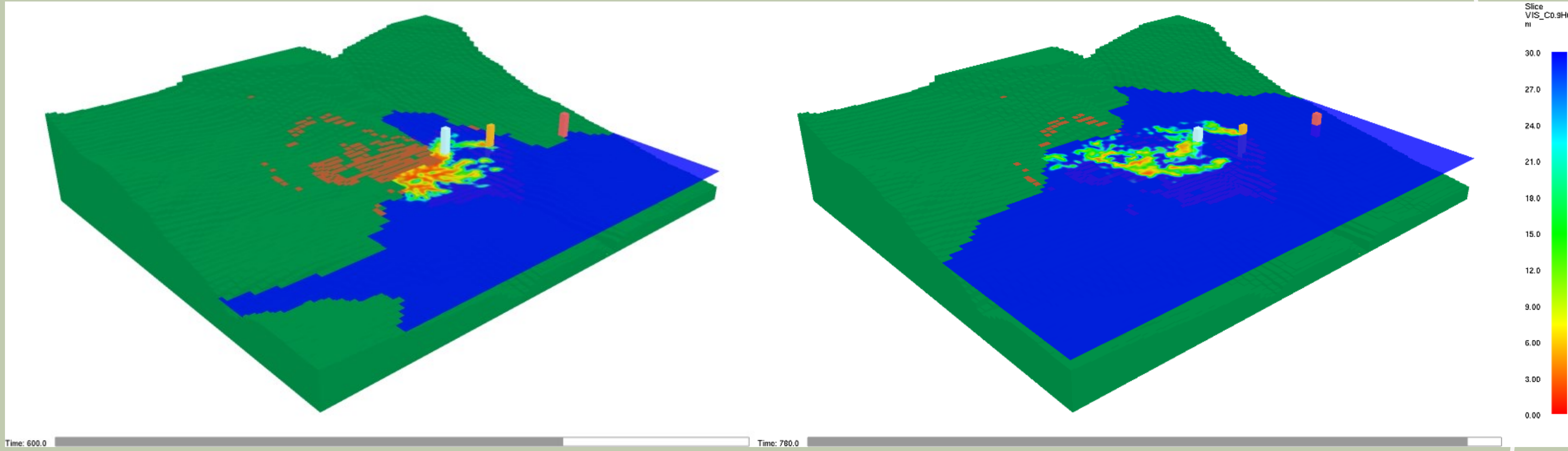
Carbon Monoxide Concentration and Air Temperature on plane Z = 110m, at 600 seconds

Infrastructures Fire Emergency Management Strategy

IT–7 Analysis of temperature field on structural parts and main systems of cable car
IT–8 Analysis of smoke and toxic species diffusion on cable car

All the physical quantities selected exhibit **significant exceedances of the threshold values** across large areas of the domain, many of which intersect with the cable car route.

It is therefore essential to **conduct a detailed assessment of the risk factors** and evaluate the need for **emergency systems and procedures specific to the case of forest fires** in the area traversed by the cabin.



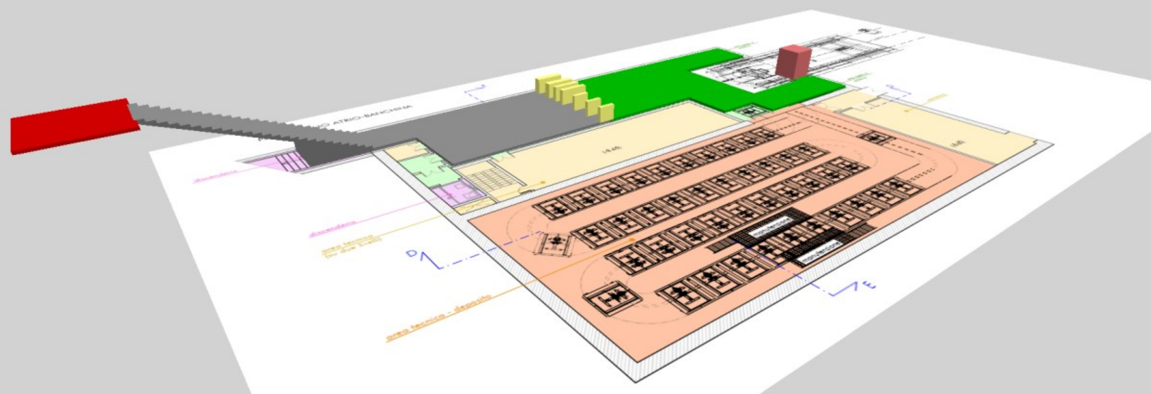
Residual visibility on plane Z = 110m, 600 seconds and Z = 150m, 780 seconds

Regarding the temperature field on the structural parts and the main safety systems of the infrastructure, no values exceeding the limits imposed by the prescriptive sections of the international regulations have been observed.
This is likely due to the greater dilution of hot smoke and the larger characteristic distances associated with this type of phenomenon.

Infrastructures Fire Emergency Management Strategy
IT–9 Analysis of passenger evacuation

Passenger evacuation analysis, often coupled with CFD analysis of fire, is an essential point of the Fire Emergency Management Strategy, as it allows to define the required safe-escape time (**RSET**, based on ISO 16738), so as to compare with the available safe-escape time (**ASET**, calculated with CFD analyses) in order to evaluate the margin of safety.

According to the operating manuals and emergency plans generally accepted, the most likely configuration in a cableway emergency typically involves the "recovery" of the cabins. This means they are automatically returned to the nearest station and subsequently taken off the line, following standardized procedures and using the system's own equipment.



Cable car mountain station, walkable surface model

The most critical analysis configuration therefore involves the evacuation of the mountain station in a worst-case crowding condition, taking into account the arriving cabins, at full capacity and unload the transported passengers.

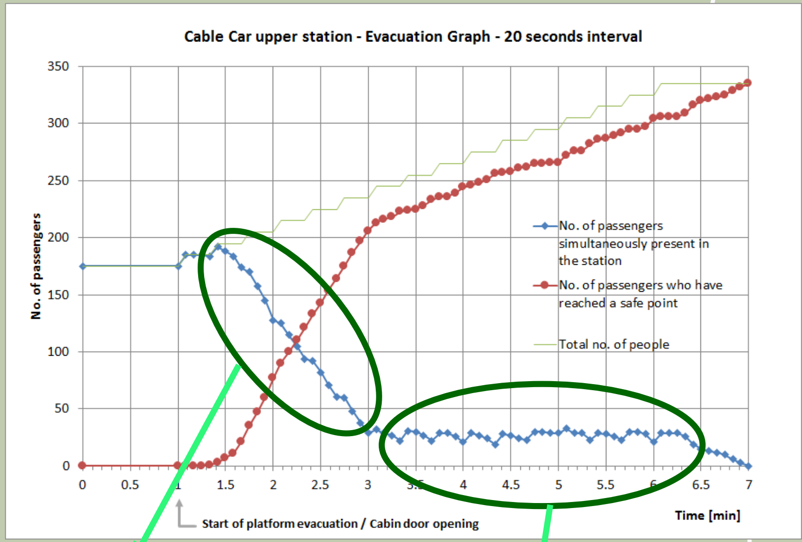
Infrastructures Fire Emergency Management Strategy

IT–9 Analysis of passenger evacuation

The primary tool for understanding the results is the **evacuation graph**, which displays, moment by moment, the total number of people present along the evacuation route and those who have reached an exit over time.

Several emergency scenarios have been analyzed, considering the pedestrian evacuation of up to 350 passengers.

The main results highlight evacuation times ranging from 4.5 to 7 minutes in total, with a maximum number of people present in the station reaching approximately 190.

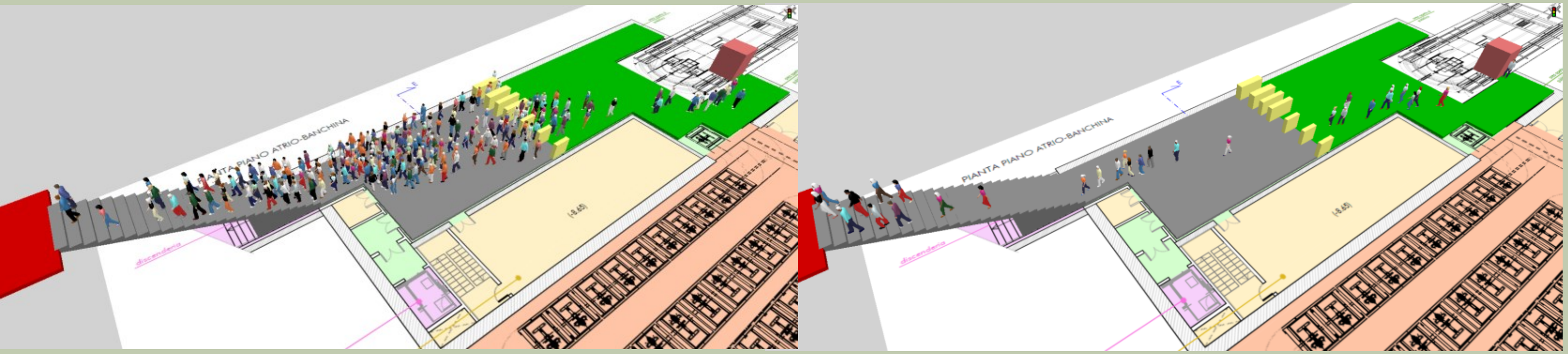


Passengers waiting on the platform

Passengers from the cabins

The results from both the fire CFD and evacuation analysis serve as support for defining the risk factors for passengers.

These data are crucial for defining mitigation measures, designing and managing safety systems, as well as rescue procedures and emergency management strategies.



Cable car upper station – 20 seconds interval – 1' 30" and 3' simulation

Infrastructures Fire Emergency Management Strategy

IT–9 Evaluation of liveability parameters during fire emergency

The aforementioned legislative framework requires, for any infrastructure, a detailed emergency plan, based on detailed and specific incident scenarios, selected through a **risk analysis** aimed at identifying and classifying hazardous events, defining acceptance criteria, and ultimately assessing whether the risk is acceptable or not.

In the risk analysis, reference is made to the definitions of **probability/frequency of occurrence** and **event consequences**, as well as the different **levels of risk** acceptance specified in the applicable regulations (EN 50126, EU Reg. 402/2013, 1136/2015, etc.).
Based on design considerations, can be stated that the emergency case of an external fire due to the combustion of forested areas, can certainly considered "**improbable**" according to the outlined framework.

However, considering the "**catastrophic**" potential consequences of the event, the resulting base risk level, should still be considered "**intolerable**".

Frequency of occurrence of a hazardous event	**Risk Levels** (EN 50126, EU 402/2013, 1136/2015)			
Frequent	Intolerable	Intolerable	Intolerable	Intolerable
Probable	Intolerable	Intolerable	Intolerable	Intolerable
Occasional	Tolerable	Intolerable	Intolerable	Intolerable
Remote	Tolerable	Tolerable	Intolerable	Intolerable
Improbable	Negligible	Tolerable	Tolerable	**Intolerable**
Incredible (highly improbable)	Negligible	Negligible	Negligible	Negligible
	Insignificant	**Marginal**	**Critic**	**Catastrophic**
	Severity Levels of Hazard Consequence			

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This implies that **the risk of external fire from forest sources shall be incorporated into the safety design process**, with standardized studies, provisions, systems and procedures aimed at reducing the risk.

In our case, it is very difficult to intervene on the frequency of occurrence, as it is already at the “improbable” level, considering the procedures related to vehicle circulation and the safety measures already in place and prescribed by regulations.

Example of deforestation of the area surrounding the cable car

It is also hard to imagine that an intervention on the source of the hazard, the forest area, could have such an impact as to sharply reduce the frequency, unless deforestation of the area surrounding the cable car is considered.
This option is obviously **not feasible** in our case, for a long list of reasons.

It is therefore necessary, to **intervene primarily on the cableway side to reduce the risk level**, both during the design phase and in the operational phase.

So, **it is necessary to plan for appropriate system provisions** (monitoring, detection, signaling, alerting, and automatic emergency management systems), specific operational methods and emergency procedures **aimed at mitigating or reducing the risk**.

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The new risk factor is characterized by an extreme variability in possible ignition points, which are external and sometimes distant from the infrastructure itself, as well as a high variability in fire development scenarios and their potential effects on the safety of both the infrastructure and individuals.

This implies that special attention must be given to systems and procedures related to the **early detection and characterization of the event** from the very first moments, including **monitoring, event detection, signaling, alerting, and automatic emergency management systems**.

A non-exhaustive list of safety systems generally considered in the design of mass transportation systems and affected by this issue:

- **Automatic fire detection and alarm systems**
- **Remote surveillance systems**
- **Voice alarm systems**
- **Intercom / Communication system**
- **General safety management system**

There are also other systems whose operation remains confined to the infrastructure but are affected by a different sizing and design:

- **Fire protection water systems**
- **Smoke extraction / containment systems**
- **Power supply and electrical systems**

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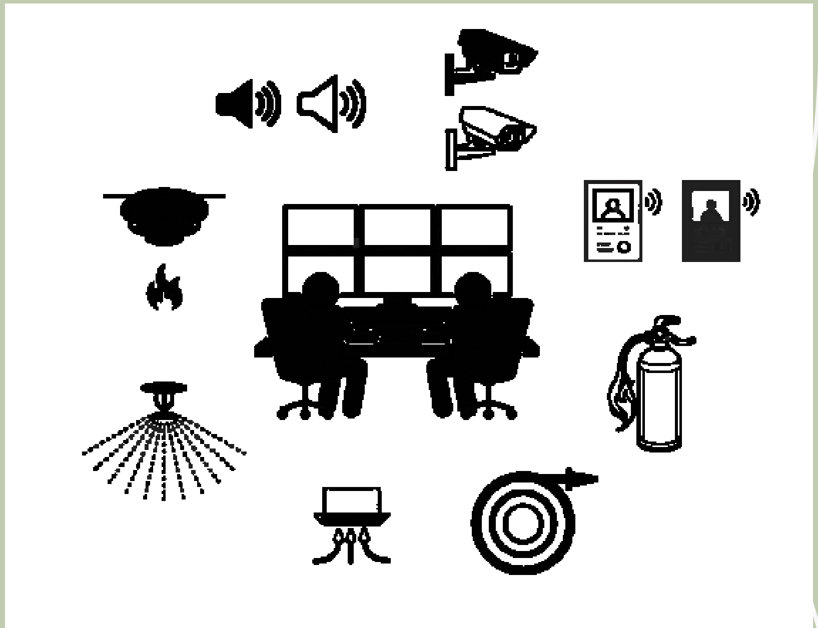
IT–10 Evaluation of innovative mitigation measures and safety systems

Generally, these systems are sized and designed to address risk factors that are internal to the infrastructure itself. The fact that in this case the risk is external and also not uniquely localizable requires a **non-standardized and decidedly innovative design approach**.

- Firstly, the **extension of the operational field** of these systems can be significantly larger and more challenging than those typically considered in standard installations.
  - This requires a detection and alarm management **structure that is not limited to the infrastructure itself** but extends beyond it. This significantly impacts the sizing and design activities.
  - Great care must be taken in **integrating the various elements within the forest environment**, both in terms of **materials** and their **visual** and **ecological** impact. Of course, all materials must be non-combustible, meaning they must not contribute to the fire.
  - For some of these systems, such as video surveillance, additional aspects must also be considered, including those related to **privacy, data ownership, recording rights**.



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Further aspects, more strictly linked to the technological domain, are discussed below:

- Due to the extension of the operational field, these systems **must be fully integrated with any external systems** used by local authorities and territorial safety managers.
  - Alarm **signals must be relayed to multiple operational control centers**, including both the infrastructure's control center and those used by local authorities and territorial safety managers.
  - Appropriate **communication protocols must be implemented** to ensure intelligibility for each actors involved in the surveillance activity, as well as compliance with international standards.

- Each control center must be able to **interpret signals differently** according to their specific safety requirements; however, the **procedures and responses implemented must be integrated**, avoiding overlaps or conflicts.
  - Each system must be able to **differentiate between alarms** that can be managed solely within the infrastructure (e.g., a fire in a technical room) and those that may require coordination among multiple agencies or entities (e.g., an external wildfire).
  - On the other hand, terminals in the external areas must be capable of automatically **distinguishing detections that may impact the infrastructure** from those that do not, to prevent unnecessary redundancies in emergency procedures.

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Security measures from TREEADS Project that could be integrated into an Infrastructure detection and alarm management structure

Fire Daily Forecasting Tool: advanced deep learning models to predict fire danger for the upcoming day, based on daily measurements of critical fire-related factors.

Fire Exposure and Risk Assessment Tool: service kit for assessing fire exposure and risk, leveraging satellite time series data to provide wildfire exposure and risk insights.

Hotspot tool: to monitor hot spots, burnt areas, and smoke plumes, offering updates on fire events within the past 24 hours.

Early Warning System: an alerting service which acts pre-emptively, by consuming data from periodic and real time sources to detect the outbreak of wildfires in real time.

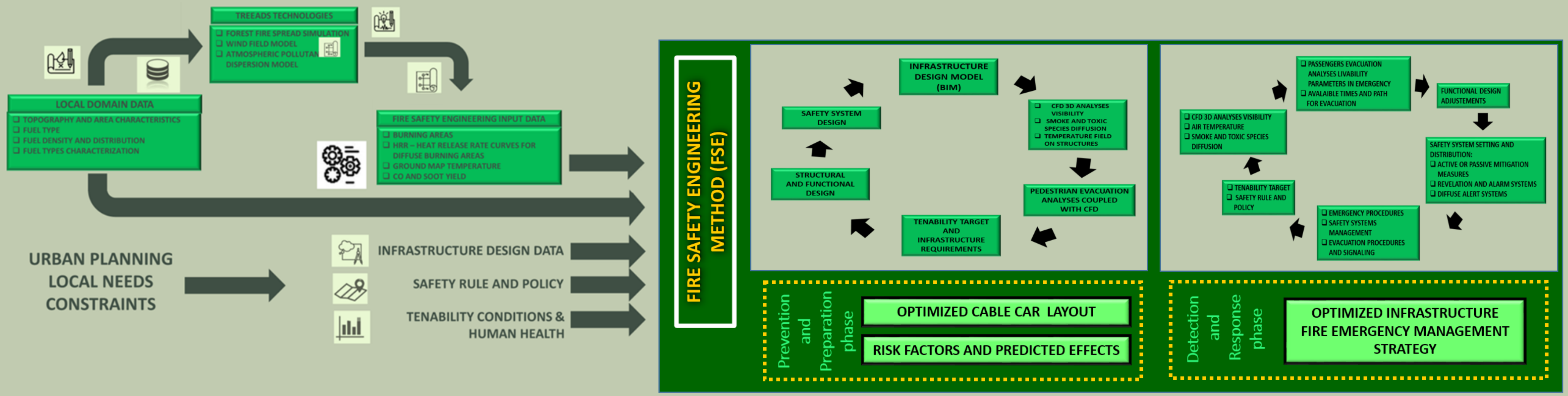
![TREEADS logo]

Infrastructures Fire Emergency Management Strategy

IT–11 Guideline development for the overall Infrastructures Fire Emergency Management Strategy - Conclusions

The activities of the whole “**Execution part 1 - Infrastructures Fire Emergency Management Strategy**” for the Italian Pilot led to the demonstration of the integrability of the tools and technologies developed in the Prevention and Preparedness Phase of the TREEADS project within a typical transport infrastructure design process, characterized by the use of the Fire Safety Engineering Method.

The main results range from the calculation of the Heat Release Rate (HRR) Curve for mass transport design in wildfire cases, to the definition of design criteria for innovative mitigation measures and safety systems.



Thank you!

Do you have any questions?

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