Automated Seismic Design of Non-structural Elements using Building Information Modelling

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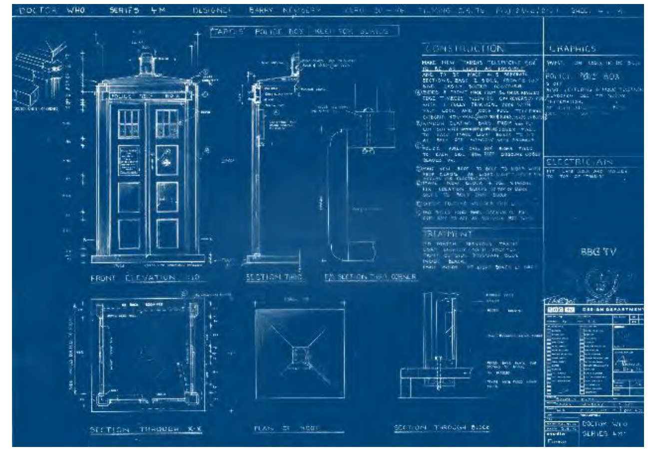
- Three main challenges associated with the seismic design of fire sprinkler piping systems:

  1. Limited information on performance.
  2. Challenges for seismic analysis procedures.
  3. Impediments to incorporating nonstructural seismic design into practice. ← Most challenging issue

- This presentation focuses on contributing to solving Challenge No. 3 using Building Information Modeling (BIM).

What is BIM?

- *"…digital representation of a built entity that allows physical and functional information to be shared amongst multiple parties in a manner that supports decision making throughout the life of a facility…"* - Associated General Contractors of America (2005)



Owners

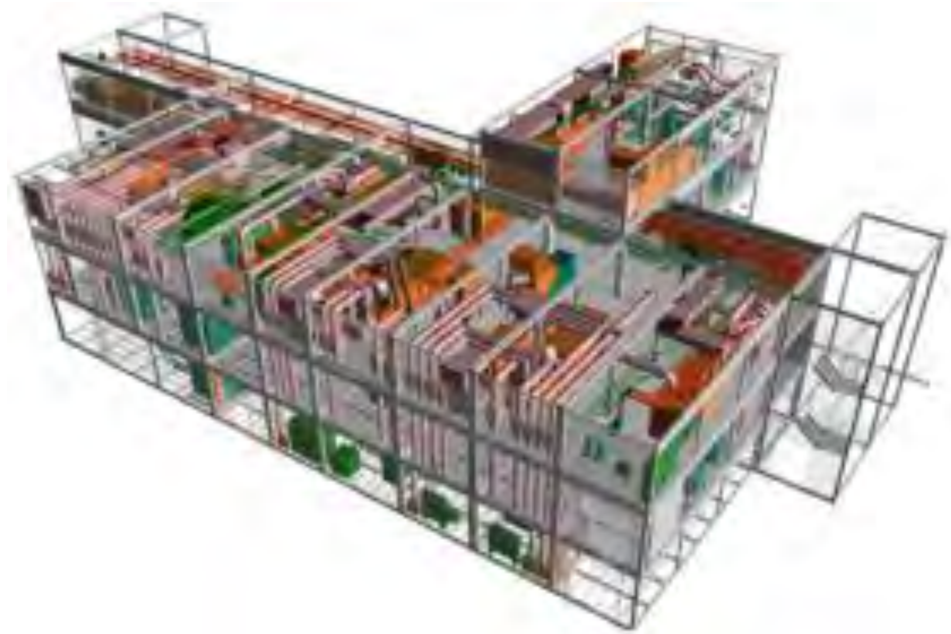
Contractors

Architects

Engineers

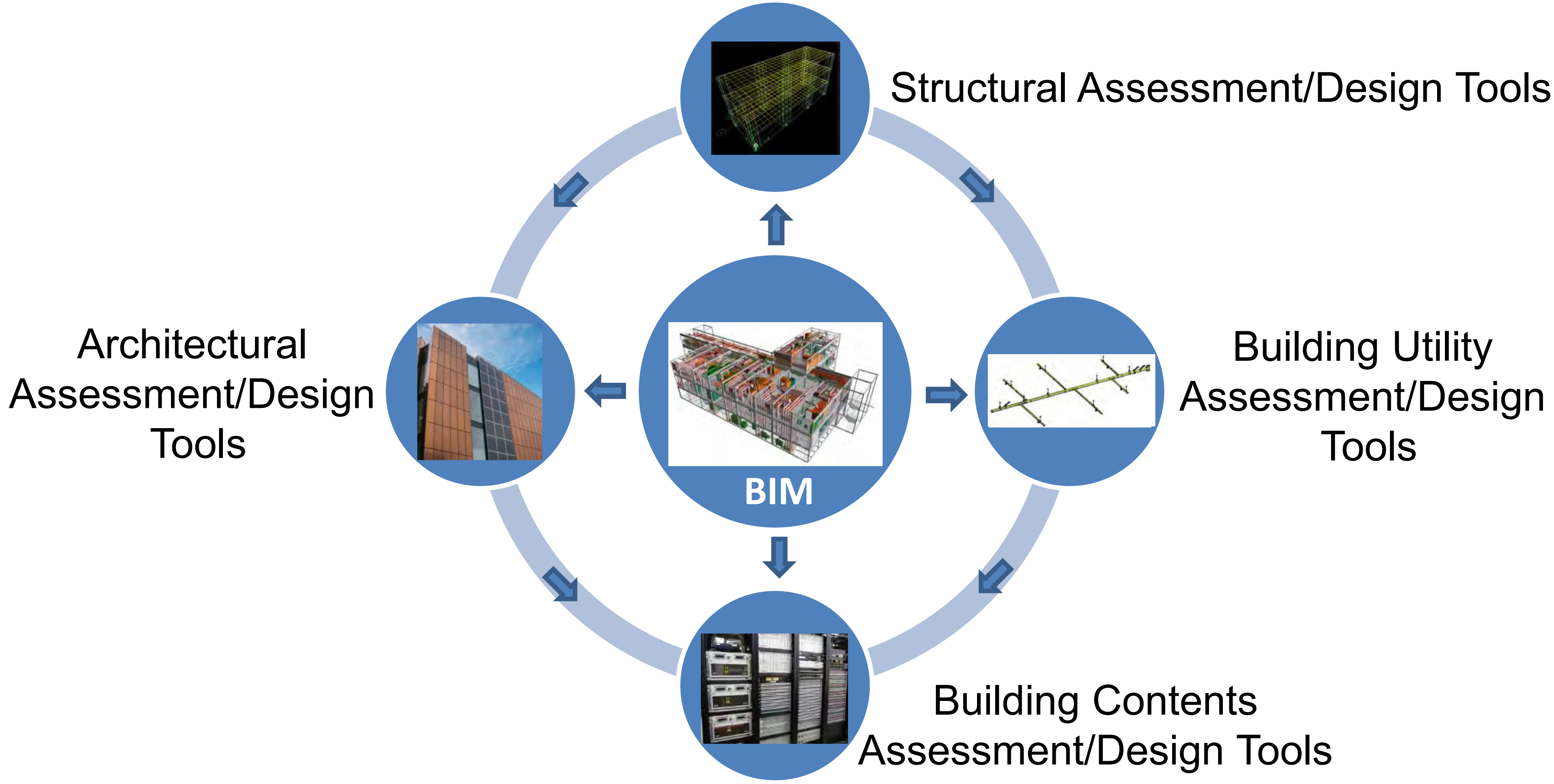
What is BIM Used for?

- During design and construction:
  - Enhance preplanning, early collaboration, and consistency of design.
  - Prevention of geometrical conflicts (clash detection).
  - Minimize change orders.
  - Improve quantity surveying, process visualisation and scheduling and cost estimation.
- During facility management:
  - Improve locations, details, and maintenance schedules of equipment.
  - Guide renovations and retrofitting.
  - Monitor and control a range of building performance parameters using sensing technology.
  - Emergency management and risk scenario planning.
- Potential use for seismic design:
  - Monitoring and control of emergency shutdown.
  - Virtual post-earthquake inspection.
  - Master building repository for exchange of information between compatible automatic seismic design and assessment tools.

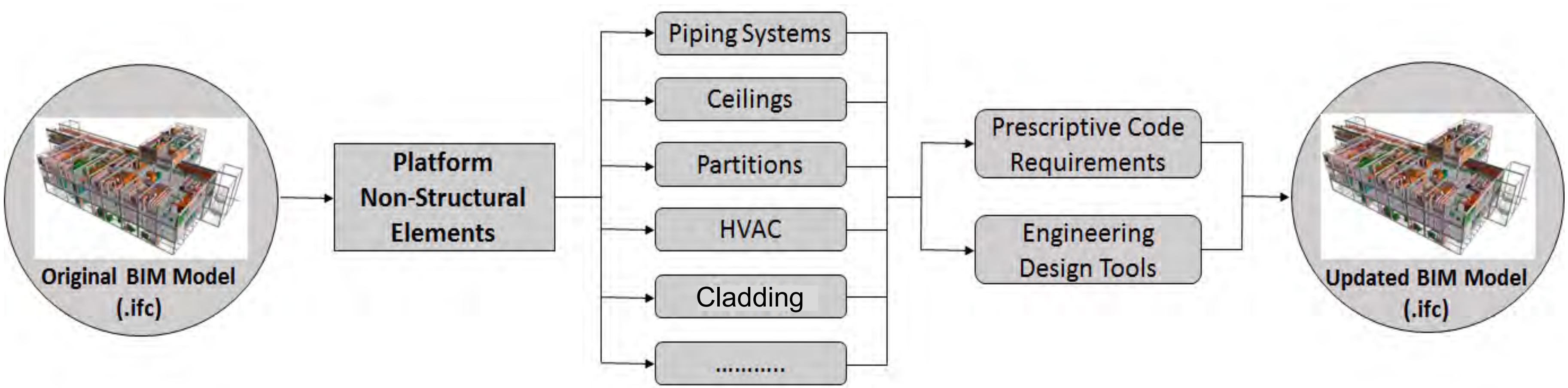


Integrated seismic assessment and design

BIM for Integrated Seismic Assessment and Design

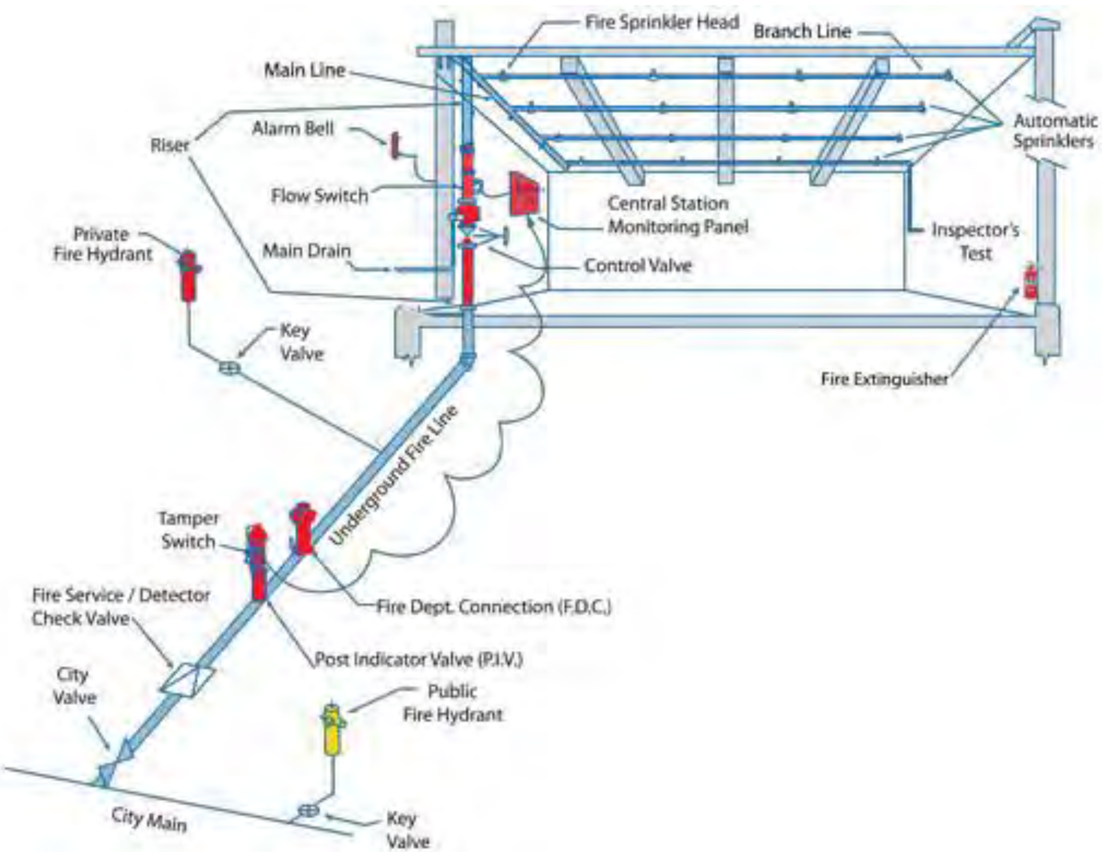


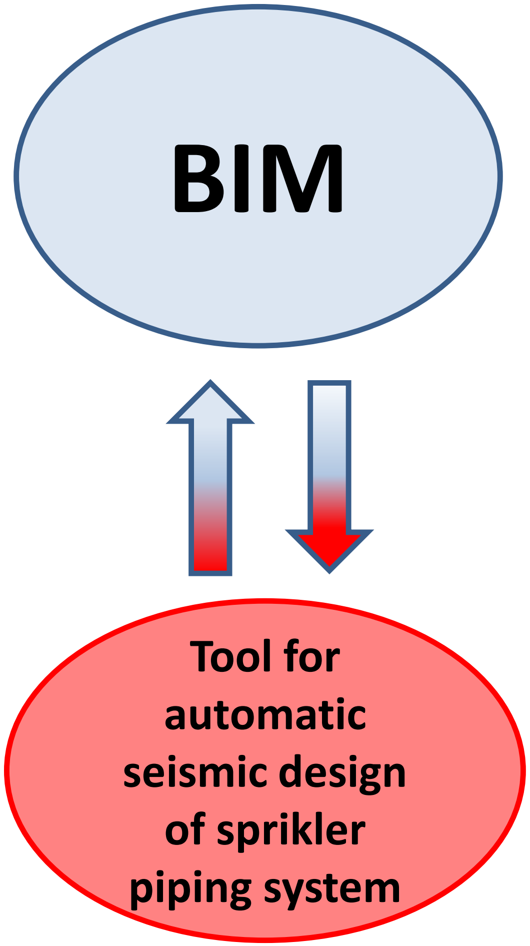
BIM FOR INTEGRATED SEISMIC ASSESSMENT AND DESIGN



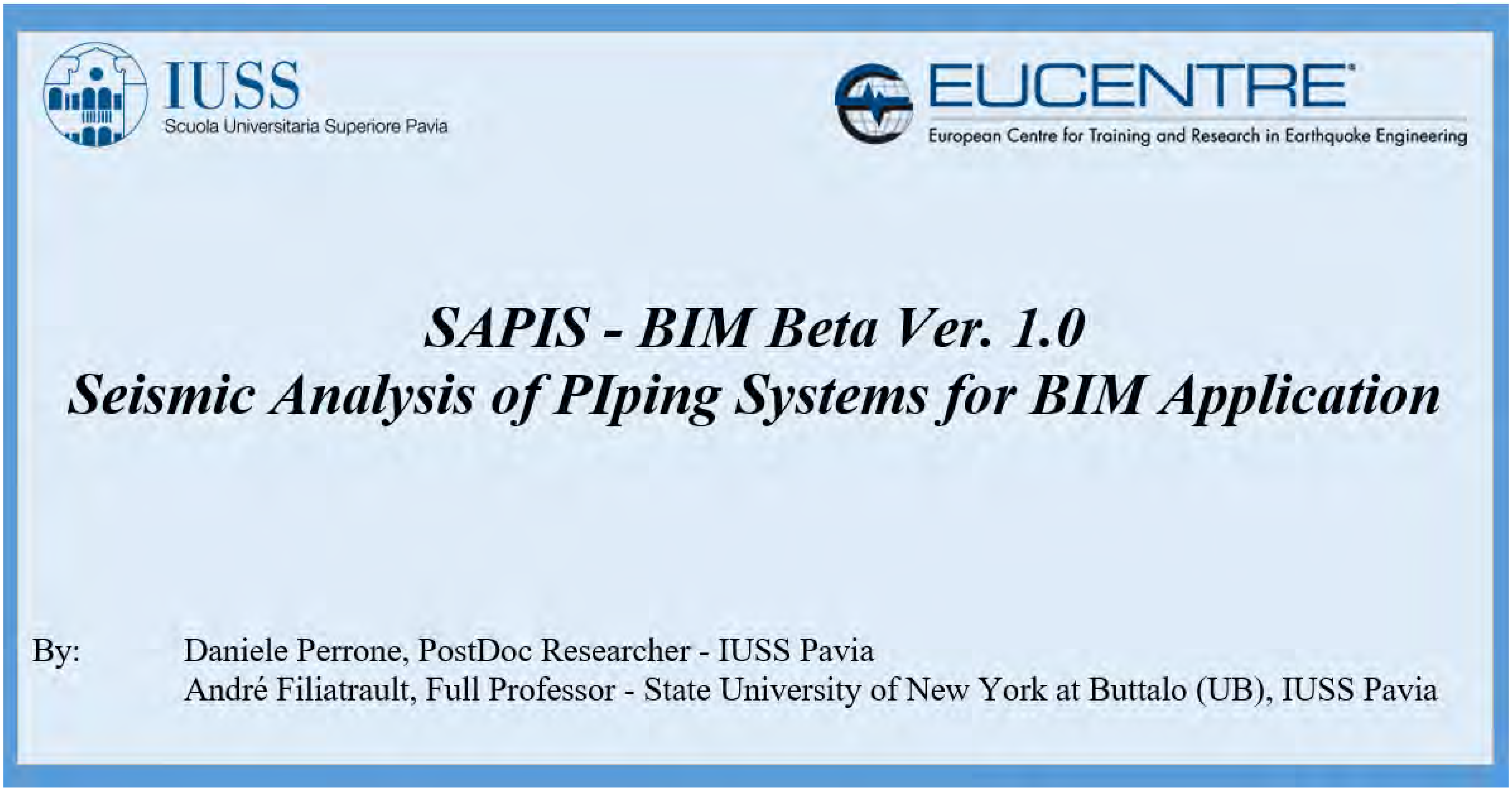
CASE STUDY:

Use of BIM for the Automatic Seismic Design of fire suppression sprinkler piping system.



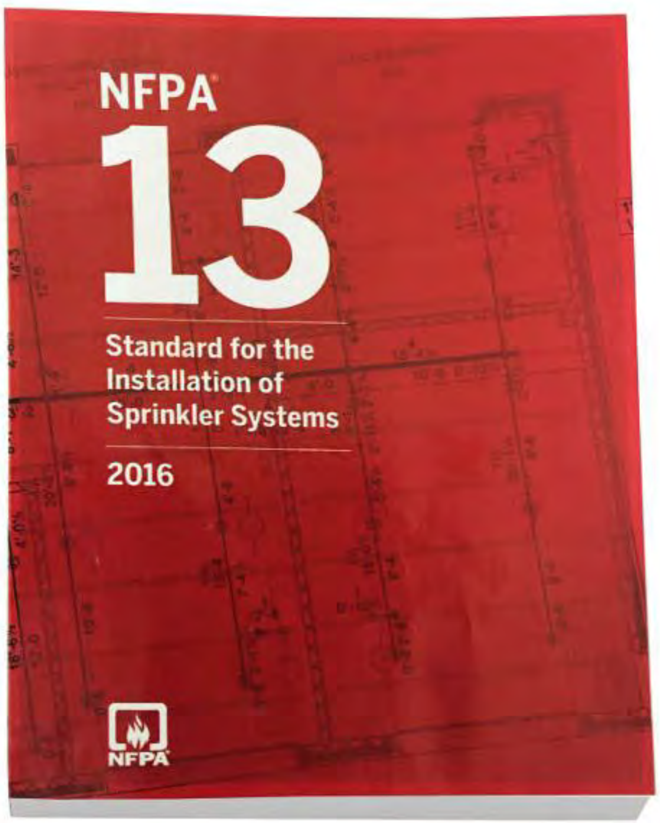


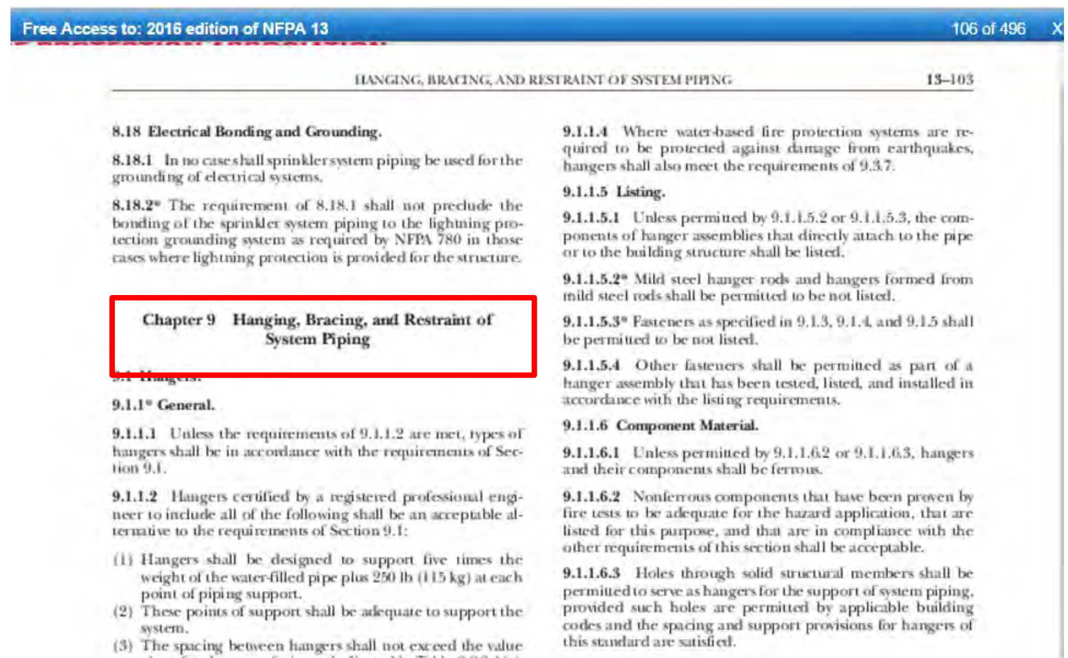
A simple tool for the automatic seismic design of sprinkler piping system using information available in BIM models has been developed.



The procedure has been developed according to the seismic provisions of the:

NFPA13 Standard for the Installation of Sprinkler Systems





Free Access to: 2016 edition of NFPA 13 — 106 of 496

HANGING, BRACING, AND RESTRAINT OF SYSTEM PIPING — 13–103

8.18 Electrical Bonding and Grounding.

8.18.1 In no case shall sprinkler system piping be used for the grounding of electrical systems.

8.18.2* The requirement of 8.18.1 shall not preclude the bonding of the sprinkler system piping to the lightning protection grounding system as required by NFPA 780 in those cases where lightning protection is provided for the structure.

Chapter 9 Hanging, Bracing, and Restraint of System Piping

9.1 Hangers.

9.1.1* General.

9.1.1.1 Unless the requirements of 9.1.1.2 are met, types of hangers shall be in accordance with the requirements of Section 9.1.

9.1.1.2 Hangers certified by a registered professional engineer to include all of the following shall be an acceptable alternative to the requirements of Section 9.1:

(1) Hangers shall be designed to support five times the weight of the water-filled pipe plus 250 lb (115 kg) at each point of piping support.
(2) These points of support shall be adequate to support the system.
(3) The spacing between hangers shall not exceed the value given for the type of pipe as indicated in Table 9.2.2.1(a).

9.1.1.4 Where water-based fire protection systems are required to be protected against damage from earthquakes, hangers shall also meet the requirements of 9.3.7.

9.1.1.5 Listing.

9.1.1.5.1 Unless permitted by 9.1.1.5.2 or 9.1.1.5.3, the components of hanger assemblies that directly attach to the pipe or to the building structure shall be listed.

9.1.1.5.2* Mild steel hanger rods and hangers formed from mild steel rods shall be permitted to be not listed.

9.1.1.5.3* Fasteners as specified in 9.1.3, 9.1.4, and 9.1.5 shall be permitted to be not listed.

9.1.1.5.4 Other fasteners shall be permitted as part of a hanger assembly that has been tested, listed, and installed in accordance with the listing requirements.

9.1.1.6 Component Material.

9.1.1.6.1 Unless permitted by 9.1.1.6.2 or 9.1.1.6.3, hangers and their components shall be ferrous.

9.1.1.6.2 Nonferrous components that have been proven by fire tests to be adequate for the hazard application, that are listed for this purpose, and that are in compliance with the other requirements of this section shall be acceptable.

9.1.1.6.3 Holes through solid structural members shall be permitted to serve as hangers for the support of system piping, provided such holes are permitted by applicable building codes and the spacing and support provisions for hangers of this standard are satisfied.

Process:

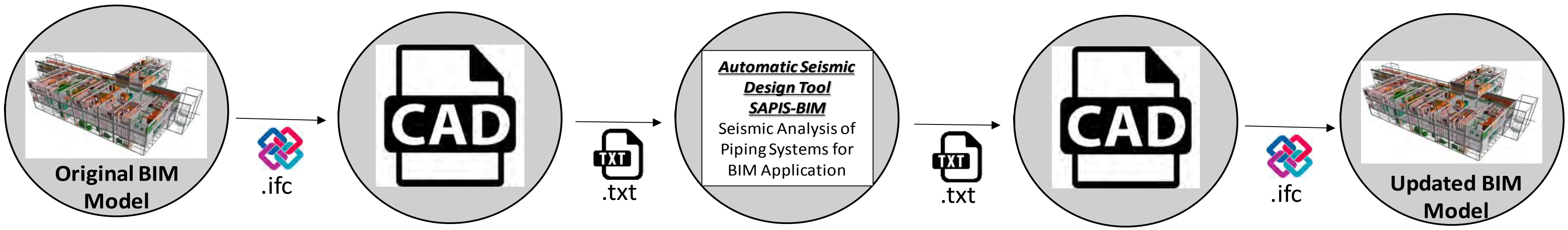
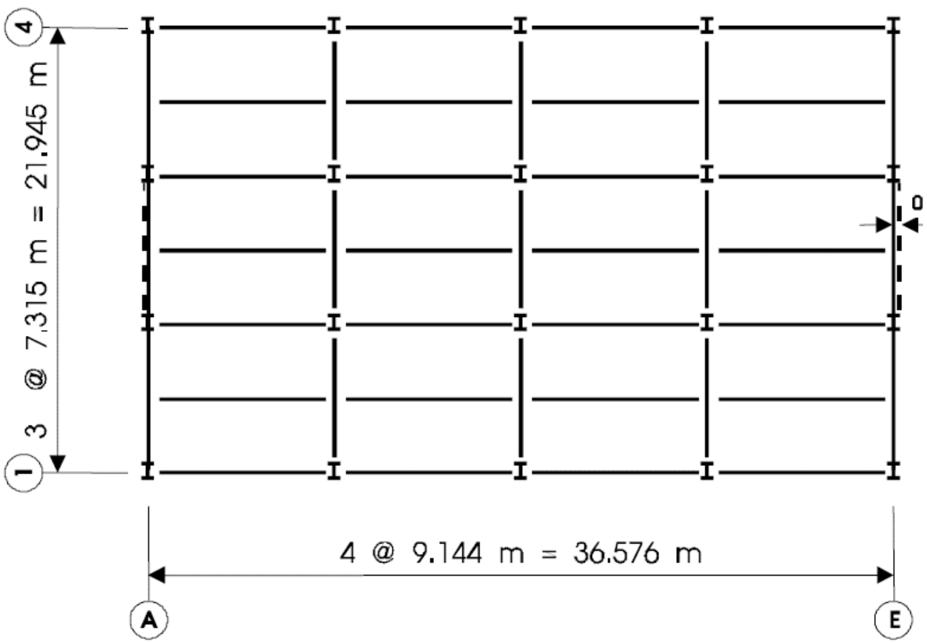
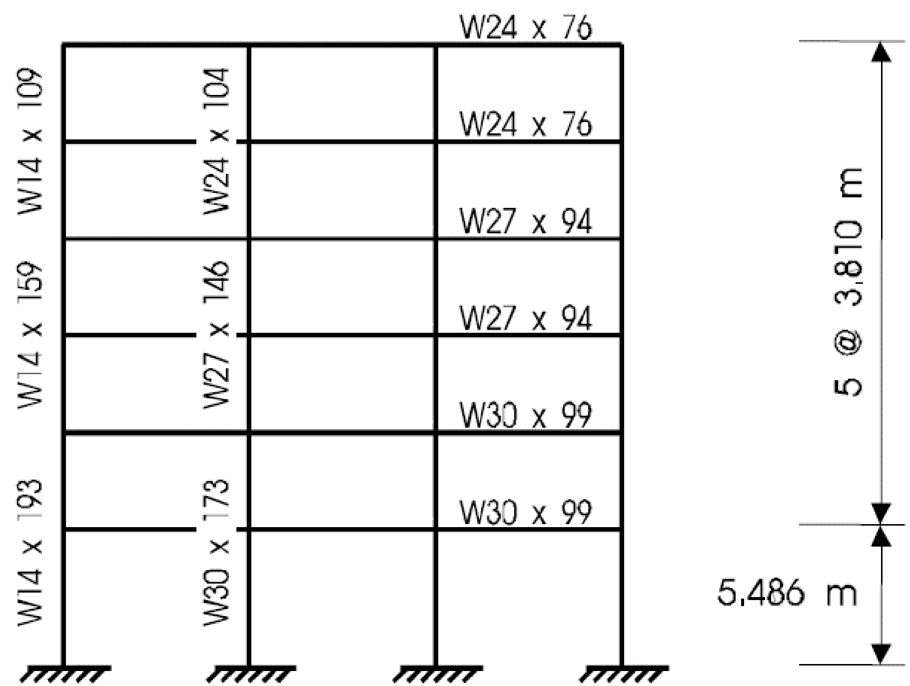

Original BIM Model
.ifc
CAD
.txt
Automatic Seismic Design Tool
SAPIS-BIM
Seismic Analysis of Piping Systems for BIM Application
.txt
CAD
.ifc
Updated BIM Model

Illustration Example:

- Six-storey steel hospital building (I_p = 1.5).
- Soil Type B in California, USA.
- Short period 2% in 50 years mapped spectral acceleration S_S = 1.5g.



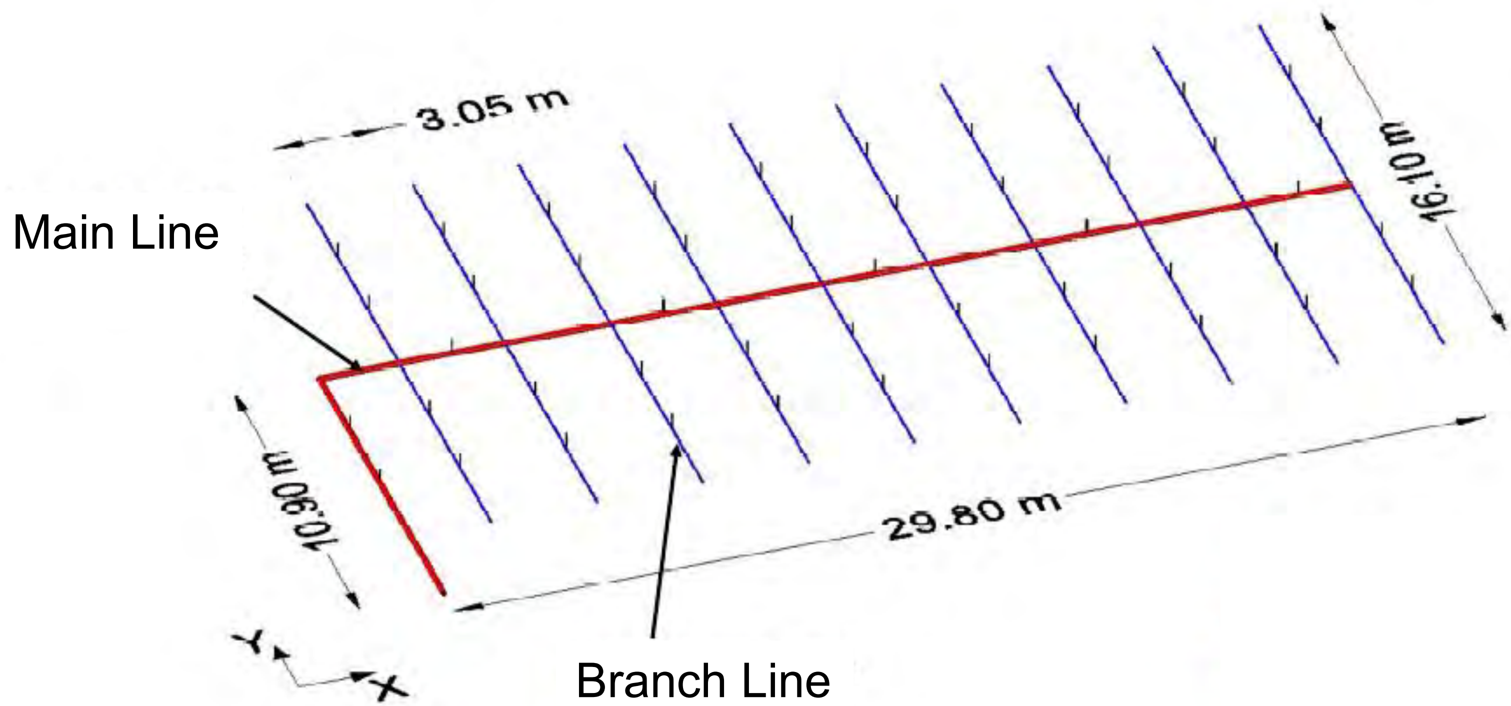
Plan View



In elevation View

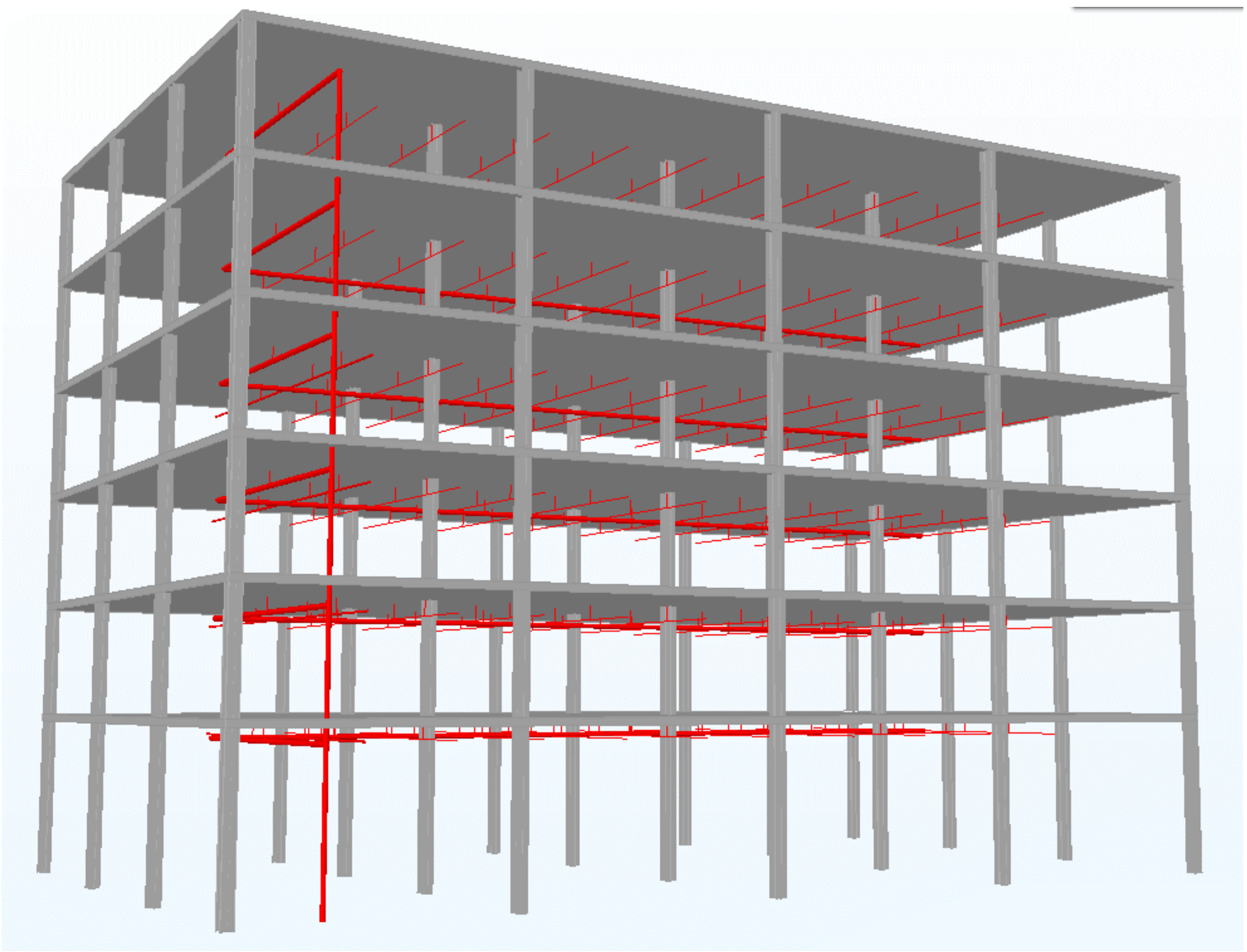
Illustrative Example:

- Sprinkler piping systems designed for gravity dead loads only.
- Main line is made of 3-1/2 in. (90 mm) schedule 10 black iron threaded pipes (R_p = 4.5).
- Branch lines are made of 1-1/4 in (32 mm) schedule 10 black iron threaded pipes (R_p = 4.5).

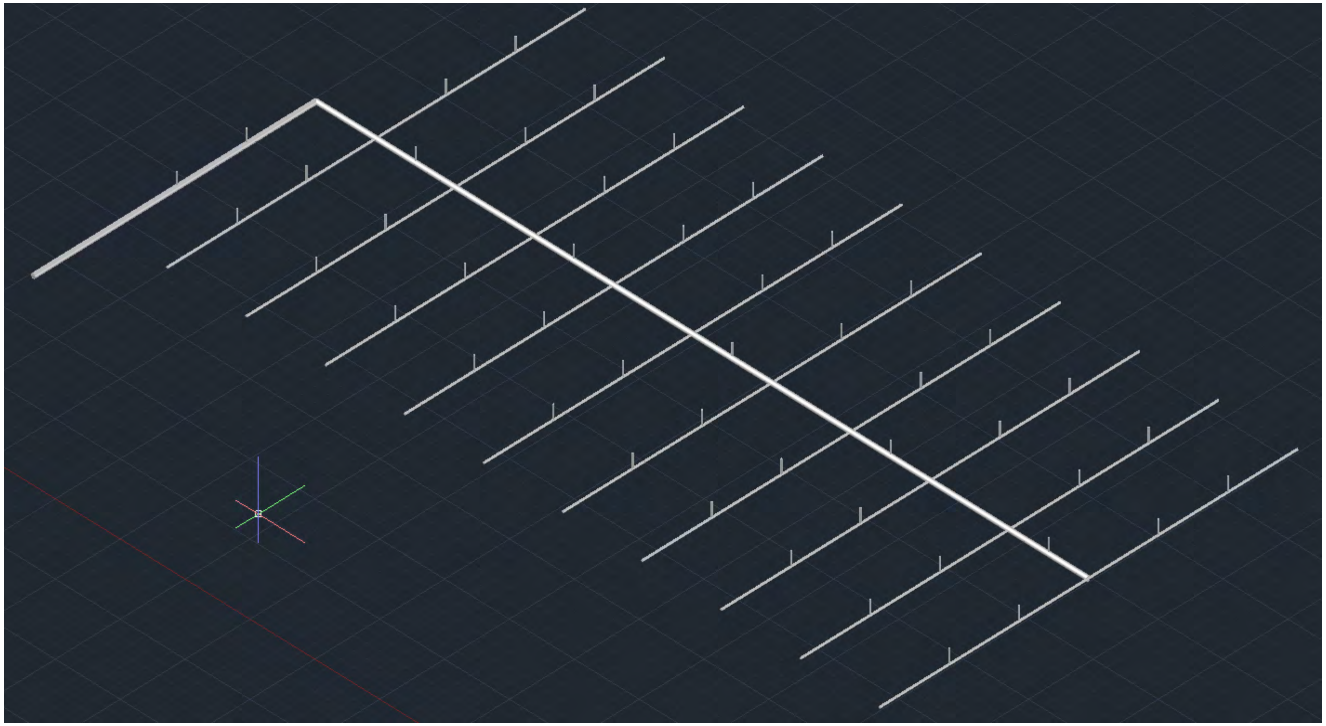


Development of the BIM Model:

Tekla BIMsight



Import of Unbraced Piping Layout from BIM model:



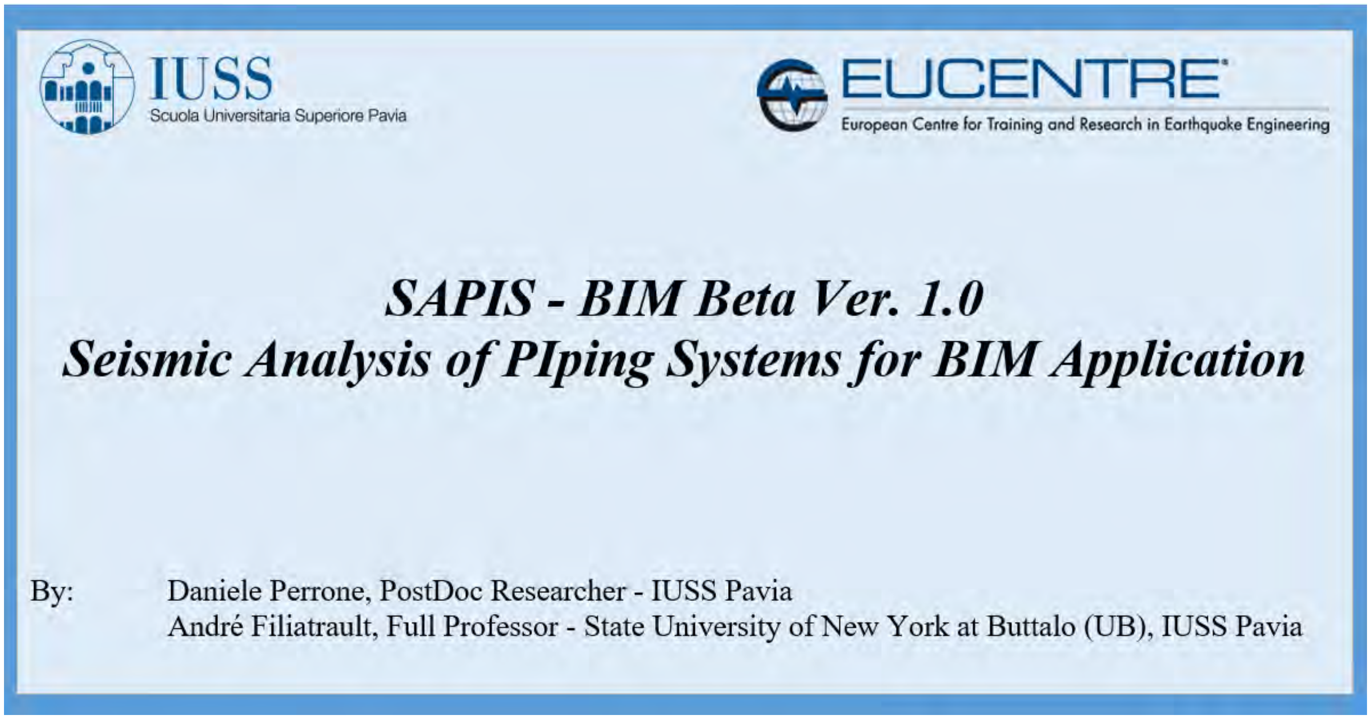
Tekla BIMsight

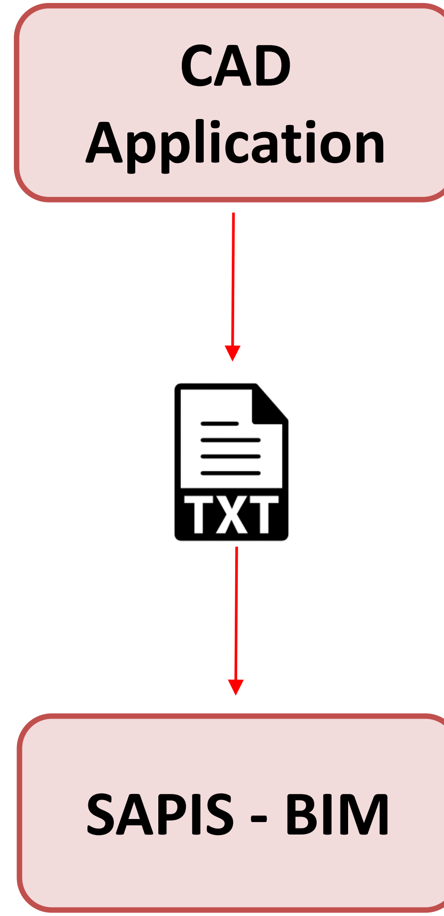
CAD

CAD Application

The layout of the unbraced sprinkler piping layout at a given floor is exported from the BIM model into the CAD application.

Automatic Seismic design of Sprinkler Piping System:



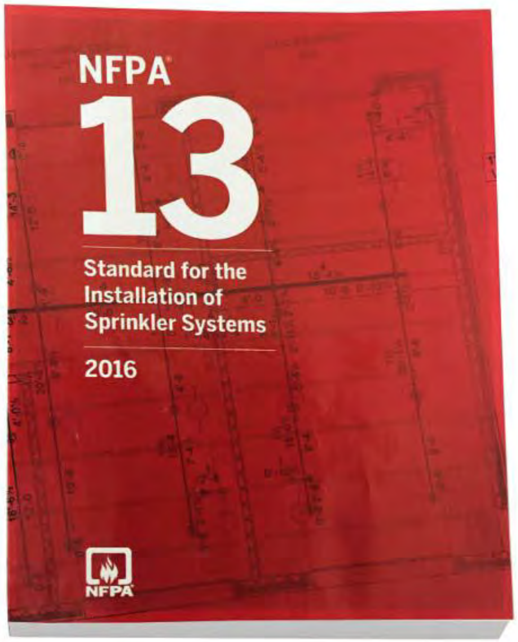


A txt file with the coordinates of the unbraced sprinkler piping layout is automatically created in the CAD application and exported into SAPIS - BIM

SAPIS – BIM tool developed as an Excel Worksheet with MS Visual Basic object-oriented applications.

Automatic Seismic Design of Sprinkler Piping System:

- Design by Rule Prescriptions
  - Prescriptive rules controlling the spacing between various types of supports to assure that the seismic stress and deformations in the piping and supports remain within permitted limits.
  - Used by SAPIS-BIM to determine the layout of pipes, and sway braces.
- Design by Analysis Prescriptions
  - Forces induced from seismic load (i.e. ASCE 7-16) and other applicable loads (e.g. gravity) are combined together to determine the design forces on the sway braces.
  - $F_{pa} = 0.7\, C_p W_p$ with three approaches to compute C_p :
    - Approach 1: According to ASCE 7-10 formula.
    - Approach 2: Simplified approach based on S_S values only.
    - Approach 3: Simplified approach with $C_p = 0.5$ for cases when S_S is not available.
  - Design forces are compared to the allowable resistance of the sway braces.
  - Used by SAPIS-BIM to determine the size of the sway braces.



Automatic Seismic Design of Sprinkler Piping System:

Flowchart of the procedure: SAPIS – BIM Ver. 1.0

1. Import unbraced sprinkler piping layout

↓

2. Define and classify pipes according to their typology

↓

3. Apply prescriptive rules of NFPA 13 and define zones of influence for sway braces

↓

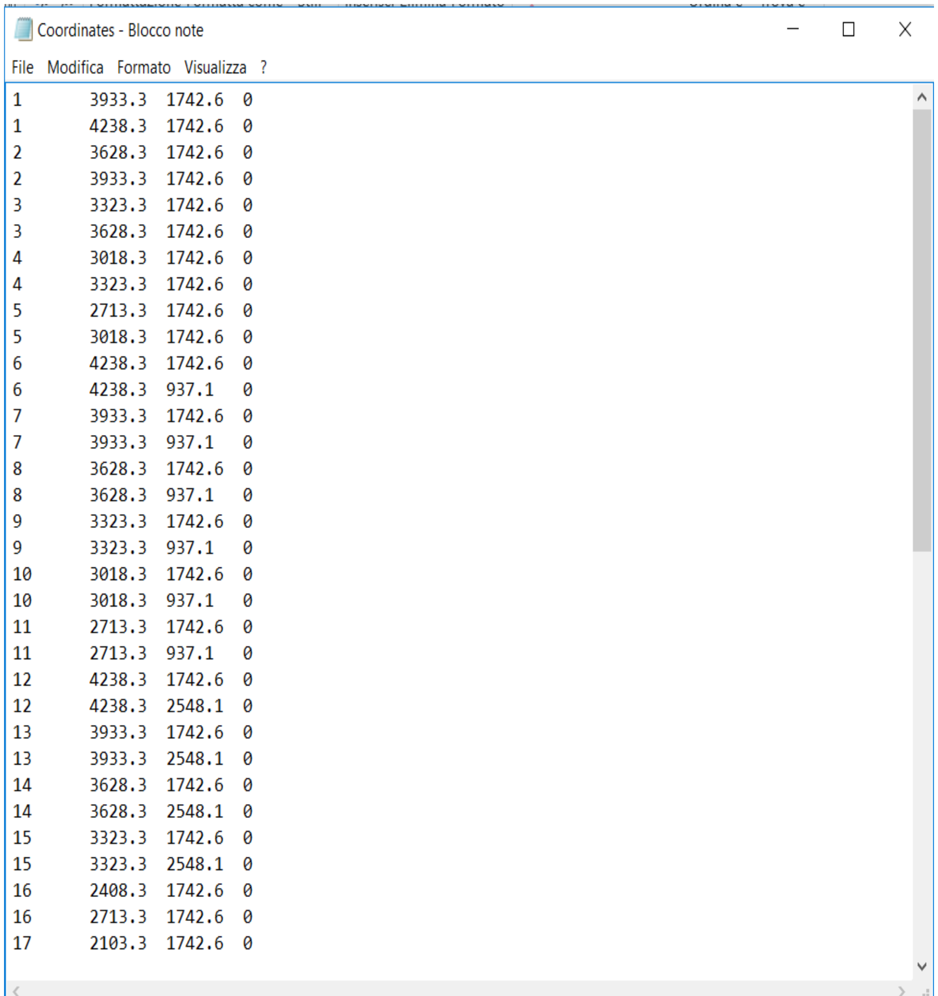
4. Apply seismic analysis procedure of NFPA13 to automatically size bracing members

↓

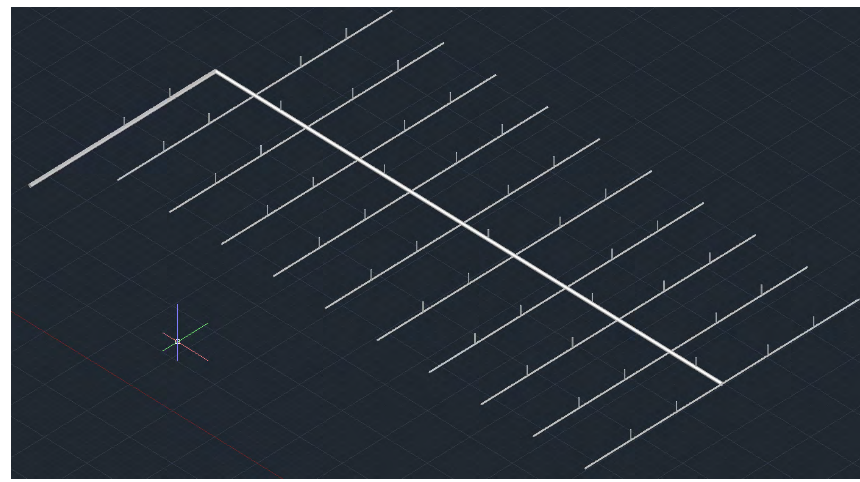
5. Export seismically braced sprinkler piping layout

Automatic Seismic Design of Sprinkler Piping System:

1. Import unbraced sprinkler piping layout


Coordinates - Blocco note
File Modifica Formato Visualizza ?

1	3933.3	1742.6	0
1	4238.3	1742.6	0
2	3628.3	1742.6	0
2	3933.3	1742.6	0
3	3323.3	1742.6	0
3	3628.3	1742.6	0
4	3018.3	1742.6	0
4	3323.3	1742.6	0
5	2713.3	1742.6	0
5	3018.3	1742.6	0
6	4238.3	1742.6	0
6	4238.3	937.1	0
7	3933.3	1742.6	0
7	3933.3	937.1	0
8	3628.3	1742.6	0
8	3628.3	937.1	0
9	3323.3	1742.6	0
9	3323.3	937.1	0
10	3018.3	1742.6	0
10	3018.3	937.1	0
11	2713.3	1742.6	0
11	2713.3	937.1	0
12	4238.3	1742.6	0
12	4238.3	2548.1	0
13	3933.3	1742.6	0
13	3933.3	2548.1	0
14	3628.3	1742.6	0
14	3628.3	2548.1	0
15	3323.3	1742.6	0
15	3323.3	2548.1	0
16	2408.3	1742.6	0
16	2713.3	1742.6	0
17	2103.3	1742.6	0



Automatic Seismic Design of Sprinkler Piping System:

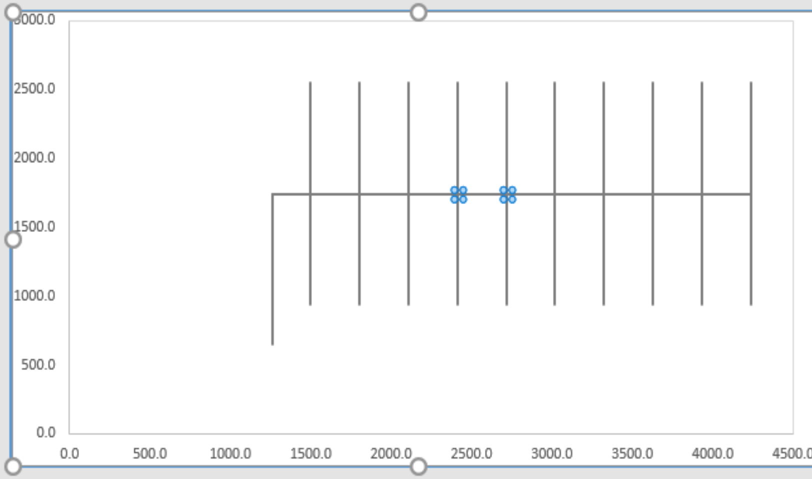
2. Define and classify pipes according to their typology

Elements

ID	X_1	X_2	Y_1	Y_2	Z_1	Z_2	Direction	Typology	Diameter
1	3933.3	4238.3	1742.6	1742.6	0	0	X	Main	90
2	3628.3	3933.3	1742.6	1742.6	0	0	X	Main	90
3	3323.3	3628.3	1742.6	1742.6	0	0	X	Main	90
4	3018.3	3323.3	1742.6	1742.6	0	0	X	Main	90
5	2713.3	3018.3	1742.6	1742.6	0	0	X	Main	90
6	4238.3	4238.3	1742.6	937.1	0	0	Y	Branch	32
7	3933.3	3933.3	1742.6	937.1	0	0	Y	Branch	32
8	3628.3	3628.3	1742.6	937.1	0	0	Y	Branch	32
9	3323.3	3323.3	1742.6	937.1	0	0	Y	Branch	32
10	3018.3	3018.3	1742.6	937.1	0	0	Y	Branch	32
11	2713.3	2713.3	1742.6	937.1	0	0	Y	Branch	32
12	4238.3	4238.3	1742.6	2548.1	0	0	Y	Branch	32
13	3933.3	3933.3	1742.6	2548.1	0	0	Y	Branch	32
14	3628.3	3628.3	1742.6	2548.1	0	0	Y	Branch	32
15	3323.3	3323.3	1742.6	2548.1	0	0	Y	Branch	32
16	2408.3	2713.3	1742.6	1742.6	0	0	X		
17	2103.3	2408.3	1742.6	1742.6	0	0	X		
18	1798.3	2103.3	1742.6	1742.6	0	0	X		
19	1493.3	1798.3	1742.6	1742.6	0	0	X		
20	3018.3	3018.3	1742.6	2548.1	0	0	Y		
21	2713.3	2713.3	1742.6	2548.1	0	0	Y		
22	2408.3	2408.3	1742.6	2548.1	0	0	Y		
23	2103.3	2103.3	1742.6	2548.1	0	0	Y		
24	1798.3	1798.3	1742.6	2548.1	0	0	Y		
25	1493.3	1493.3	1742.6	2548.1	0	0	Y		
26	2408.3	2408.3	1742.6	937.1	0	0	Y		
27	2103.3	2103.3	1742.6	937.1	0	0	Y		
28	1798.3	1798.3	1742.6	937.1	0	0	Y		
29	1493.3	1493.3	1742.6	937.1	0	0	Y		
30	1262.3	1262.3	1742.6	652.6	0	0	Y		
31	1493.3	1262.3	1742.6	1742.6	0	0	X		

Branch
Main

Piping Layout



Select the Element on the plot and assign to each element the typology ("Main" for main line and "Branch" for branch line) and the diameter (mm)

Go to the next Step

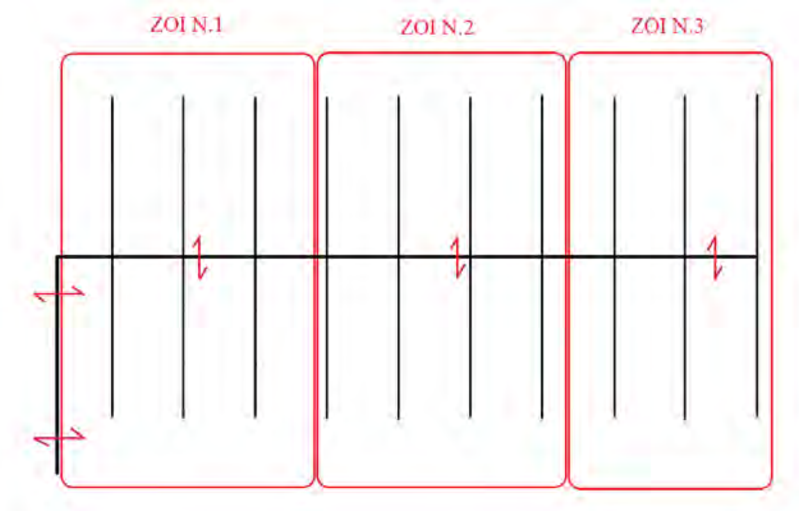
Home | DWG_Input | Pipe_Element

Automatic Seismic Design of Sprinkler Piping System:

3. Apply prescriptive rules of NFPA 13

Evaluate area of Influence

Area of Influence in terms of Length of pipes (cm)											
Main Line	Brace 1	Brace 2	Brace 3	Brace 4	Brace 5	Brace 6	Brace 7	Brace 8	Brace 9	Brace 10	Brace 11
1 - X	7597	5934	3953								



Example for transverse sway braces of the main line in the X-direction

Once the minimum number of braces and their locations are defined, the area of influence are evaluated.

Automatic Seismic Design of Sprinkler Piping System:

4. Apply seismic analysis procedure of NFPA13 (illustration for 2nd floor)

Evaluation Seismic Force

Methods of Evaluation Seismic Demand:

1. According to ASCE 07
2. Simplified procedure according to NFPA 13
3. Simplified procedure according to NFPA 13 with Cp assumed equal to 0.5

Select the Method to evaluate Seismic Force
1
1
2
3

$$F_{ph} = \frac{0.4 a_p S_{DS}}{\left(\frac{R_p}{I_p}\right)} \left(1 + 2\frac{z}{h}\right) W_p$$

Parameters for ASCE-07	
ap	2,5
Rp	4,5
Ip	1,5
z/h	0,38

$$F_{phw} = 0.7 F_{ph}$$

The three methodologies available in NFPA13 in order to evaluate the seismic force have been implemented in the procedure

Automatic Seismic Design of Sprinkler Piping System:

4. Apply seismic analysis procedure of NFPA13 (illustration for 2nd floor)

Evaluation Weight for braces in X direction	
Select Diameter of the Main Line	90
Select Diameter of the Branch Line	32
Evaluation Weight for braces in Y direction	
Select Diameter of the Main Line	90
Select Diameter of the Branch Line	32

Calculate Cp	0,7	
H_{Piping}	800	mm
ϑ	45	°
Length	1131,42	
Ss	1,5	

Braces Type	Pipe Schedule 40
Diameter	25
Slenderness	100
Calculate Max Horizontal Load Braces (kN)	19,8

Horizontal Seismic Demand on each brace oriented in the Y-direction and attached to the main line in the X-direction (kN)											
ID Main Line	**Brace 1**	**Brace 2**	**Brace 3**	**Brace 4**	**Brace 5**	**Brace 6**	**Brace 7**	**Brace 8**	**Brace 9**	**Brace 10**	**Brace 11**
1 - X	1,89	1,58	1,05								
2 - X											
3 - X											
4 - X											
5 - X											
6 - X											
7 - X											
8 - X											
9 - X											
10 - X											
Horizontal Seismic Demand on each brace oriented in the X-direction and attached to the main line in the Y-direction (kN)											
ID Main Line	**Brace 1**	**Brace 2**	**Brace 3**	**Brace 4**	**Brace 5**	**Brace 6**	**Brace 7**	**Brace 8**	**Brace 9**	**Brace 10**	**Brace 11**
1 - Y	0,37	0,37									

Automatic Seismic Design of Sprinkler Piping System:

4. Apply seismic analysis procedure of NFPA13 (illustration for 2nd floor)

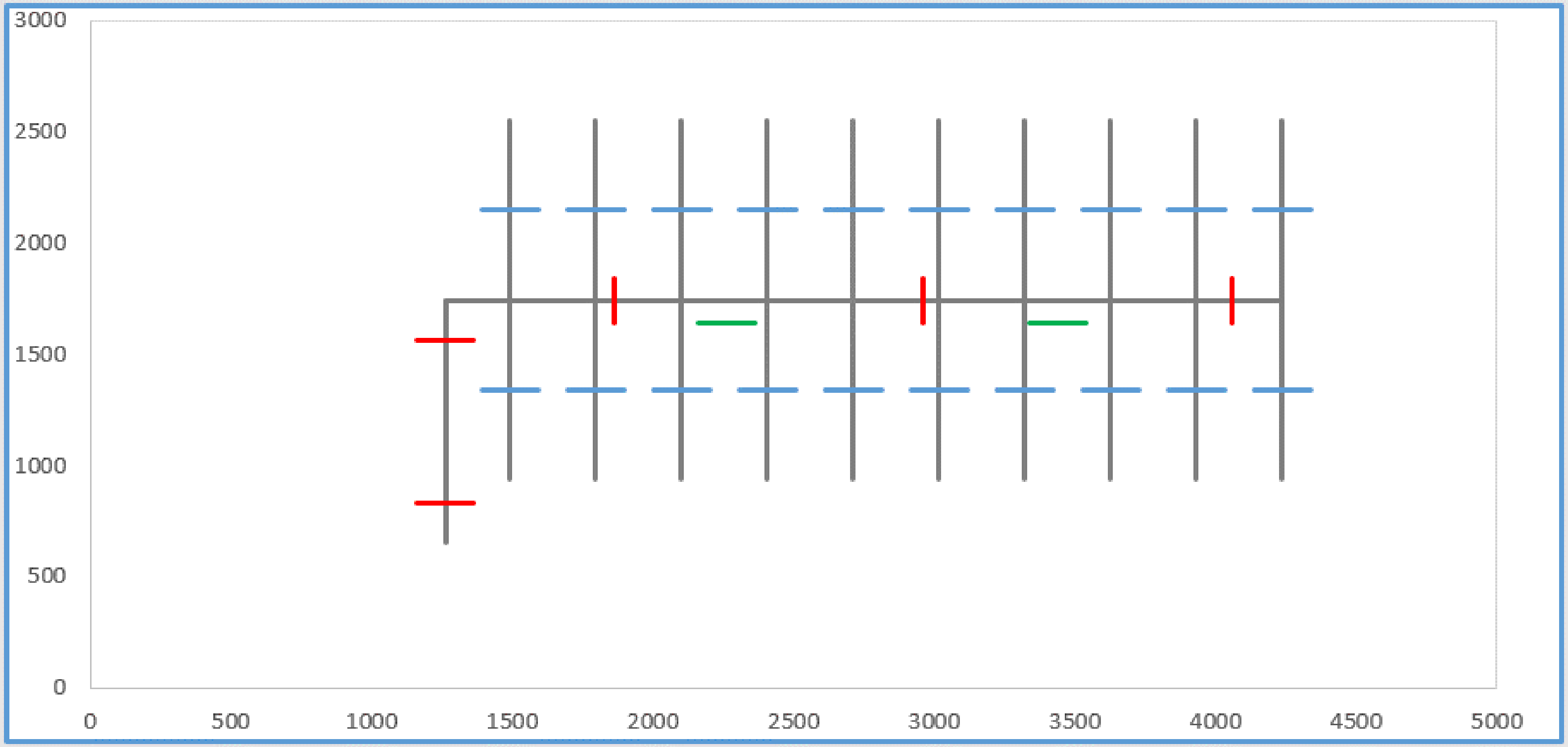
Verification of braces oriented in the Y-direction and attached to the main line in the X-direction (kN)											
ID Main Line	Brace 1	Brace 2	Brace 3	Brace 4	Brace 5	Brace 6	Brace 7	Brace 8	Brace 9	Brace 10	Brace 11
1 - X	ok	ok	ok								
2 - X											
3 - X											
4 - X											
5 - X											
6 - X											
7 - X											
8 - X											
9 - X											
10 - X											

Verification of braces oriented in the X-direction and attached to the main line in the Y-direction (kN)											
ID Main Line	Brace 1	Brace 2	Brace 3	Brace 4	Brace 5	Brace 6	Brace 7	Brace 8	Brace 9	Brace 10	Brace 11
1 - Y	ok	ok									
2 - Y											
3 - Y											
4 - Y											
5 - Y											
6 - Y											
7 - Y											
8 - Y											
9 - Y											
10 - Y											

The capacity to demand ratio is automatically calculated. If the capacity is not adequate, the typology of the braces can be modified. An optimization of the braces size can be also performed.

Automatic Seismic Design of Sprinkler Piping System:

5. Export seismically braced sprinkler piping layout

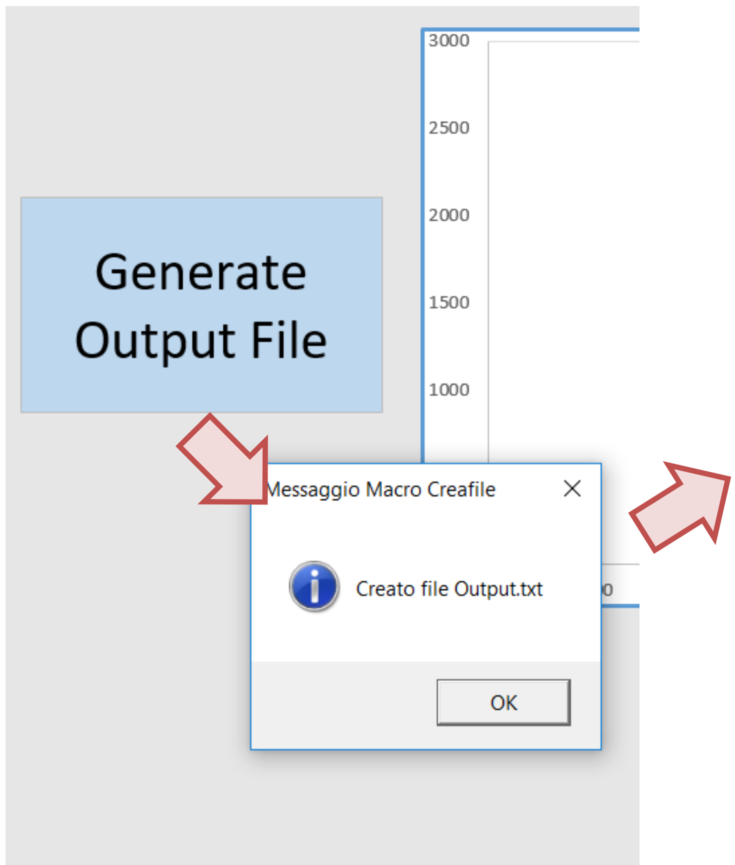


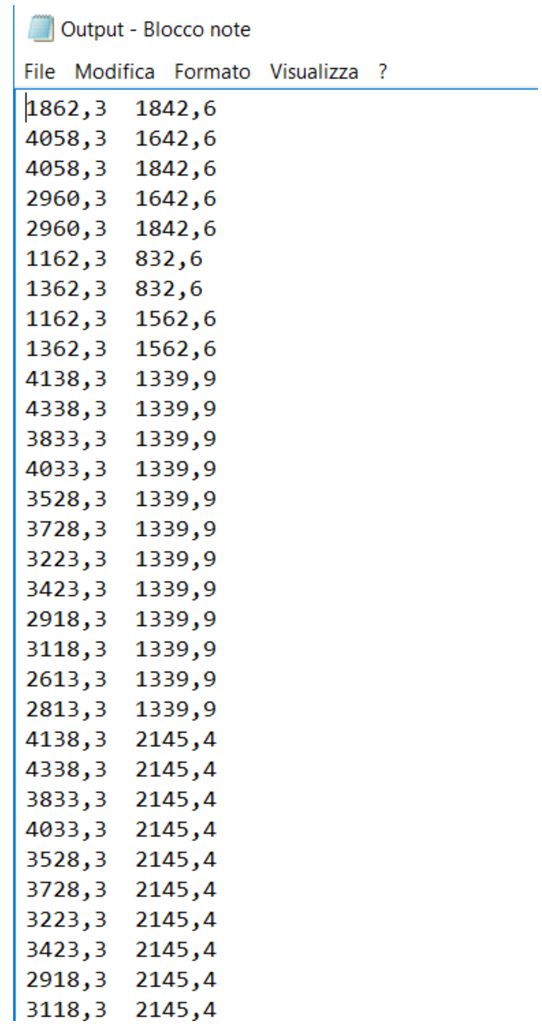
Details about the Bracing System			
		Typology	Diameter
Main Line	**Transverse**	***Pipe Schedule 40***	***25***
	Londitudinal	***Pipe Schedule 40***	***25***
Branch	**Transverse**	***Pipe Schedule 40***	***No.12.44 lb (200kg)***

Automatic Seismic Design of Sprinkler Piping System:

5. Export seismically braced sprinkler piping layout

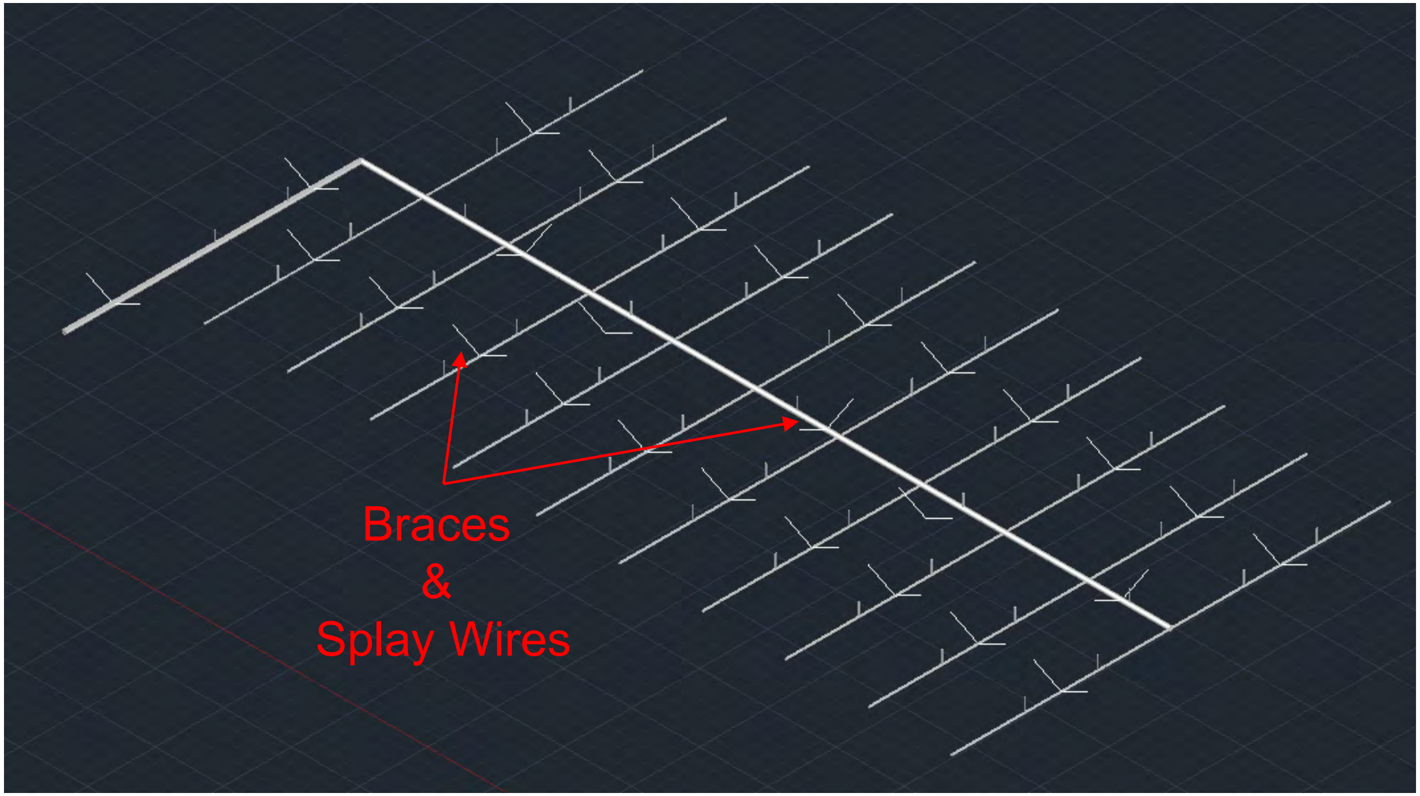
1862,3	1642,6
1862,3	1842,6
4058,3	1642,6
4058,3	1842,6
2960,3	1642,6
2960,3	1842,6
1162,3	832,6
1362,3	832,6
1162,3	1562,6
1362,3	1562,6
4138,3	1339,9
4338,3	1339,9
3833,3	1339,9
4033,3	1339,9
3528,3	1339,9
3728,3	1339,9
3223,3	1339,9
3423,3	1339,9
2918,3	1339,9
3118,3	1339,9
2613,3	1339,9
2813,3	1339,9
4138,3	2145,4
4338,3	2145,4
3833,3	2145,4
4033,3	2145,4
3528,3	2145,4

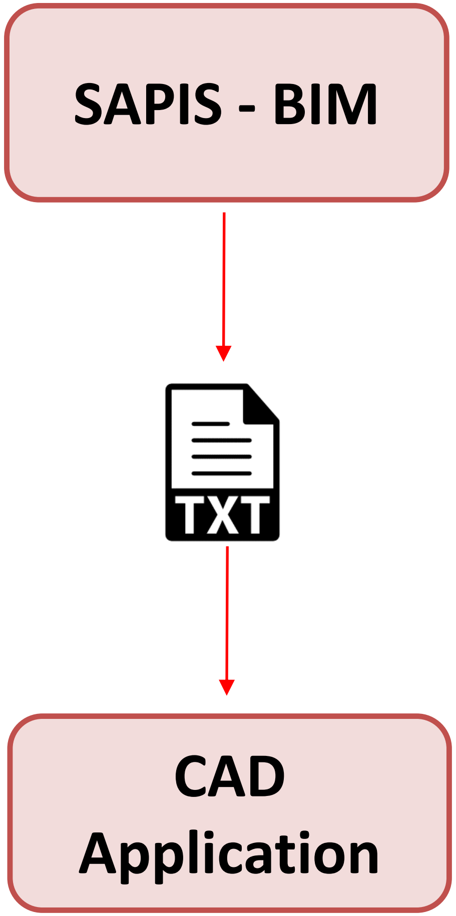



Output - Blocco note
File Modifica Formato Visualizza ?

1862,3	1842,6
4058,3	1642,6
4058,3	1842,6
2960,3	1642,6
2960,3	1842,6
1162,3	832,6
1362,3	832,6
1162,3	1562,6
1362,3	1562,6
4138,3	1339,9
4338,3	1339,9
3833,3	1339,9
4033,3	1339,9
3528,3	1339,9
3728,3	1339,9
3223,3	1339,9
3423,3	1339,9
2918,3	1339,9
3118,3	1339,9
2613,3	1339,9
2813,3	1339,9
4138,3	2145,4
4338,3	2145,4
3833,3	2145,4
4033,3	2145,4
3528,3	2145,4
3728,3	2145,4
3223,3	2145,4
3423,3	2145,4
2918,3	2145,4
3118,3	2145,4

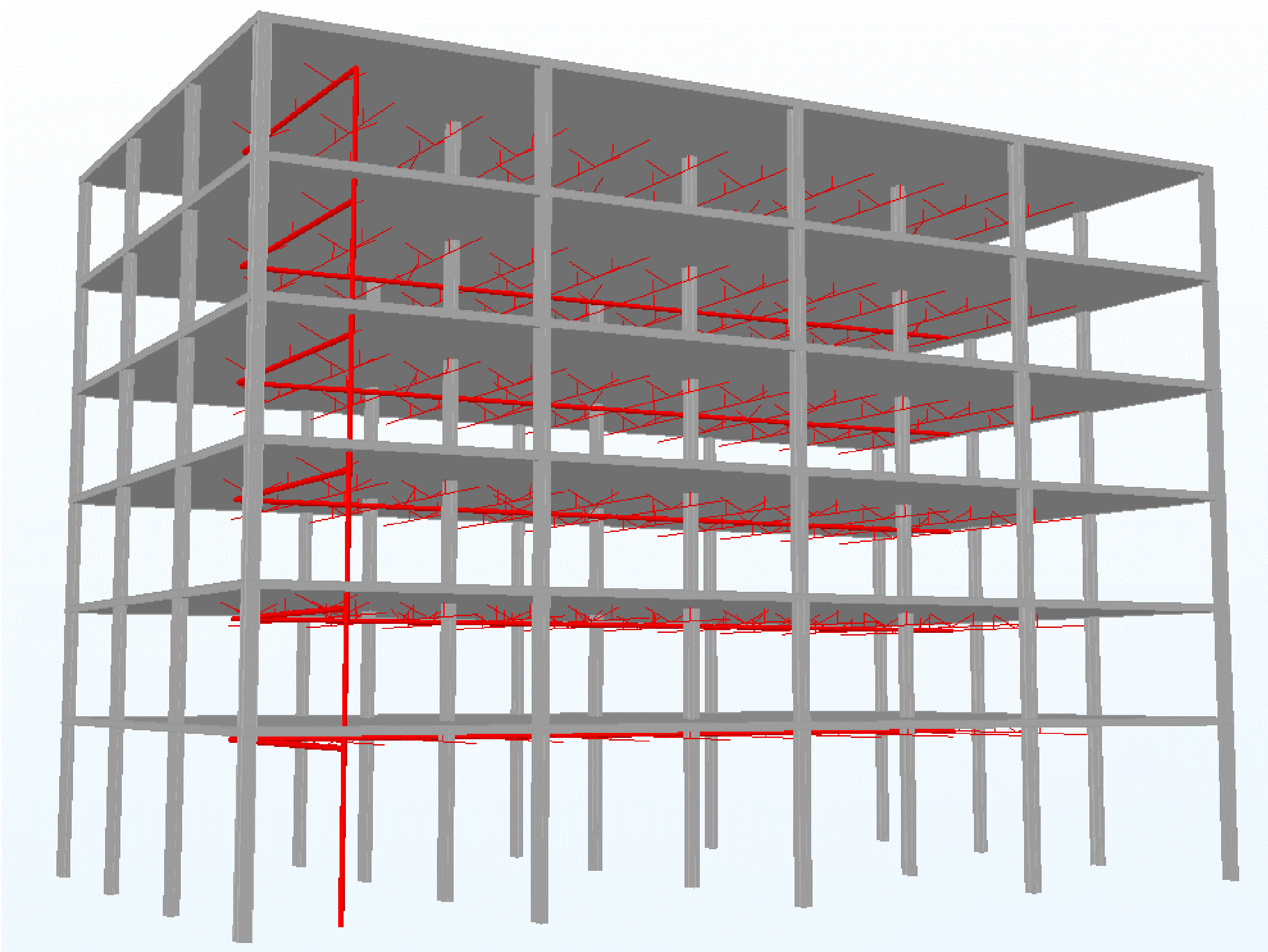
Export of Seismically Braced Piping Layout:

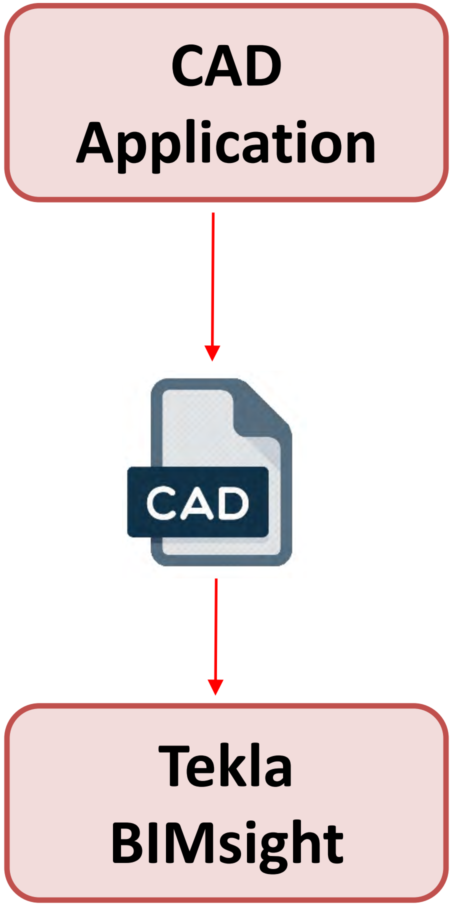




The coordinates of the braces are exported in CAD file of the piping layout.

Export of Seismically Braced Piping Layout in BIM Model:



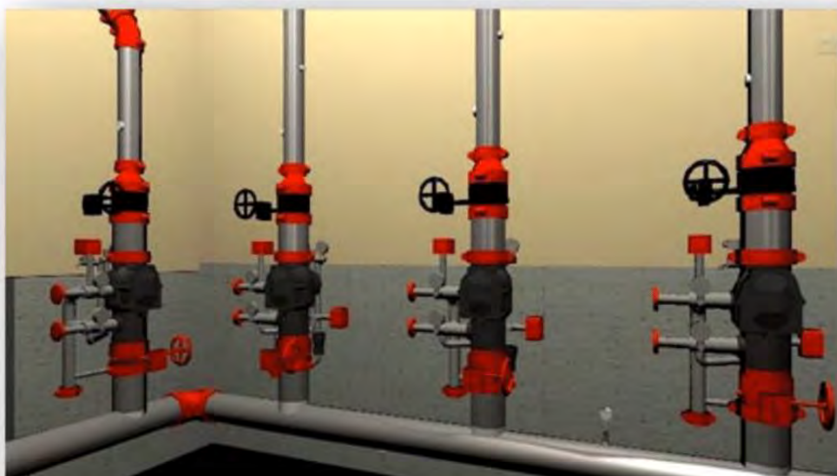


Export of Seismically Braced Piping Layout in BIM Model:

Tekla BIMsight

Victaulic since 1919

Goal: Build what you model



Source: Verlinden, K. 2018. “BIM and VR in FP Design,” 2018 Fire Sprinkler International Conference, Stockholm, Sweden.

Conclusions

- Simple Excel based tool (SAPIS – BIM) has been created for the automatic seismic design of sprinkler piping systems.
- SAPIS – BIM imports coordinates of unbraced sprinkler piping systems from a BIM model through a CAD application.
- SAPIS – BIM exports coordinates of seismically braced sprinkler piping system.
- Similar BIM compatible tools could be created for the automatic seismic design of other typologies of nonstructural components to help lift some of the impediments to incorporating nonstructural seismic design into practice.

Thank you!

What the client wanted.

The architect's solution.

The structural engineer's solution.

The non-structural engineer's Solution.