FIG WORKING WEEK 2019

22–26 April, Hanoi, Vietnam

"Geospatial Information for a Smarter Life and Environmental Resilience"

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PLATINUM SPONSORS esri Trimble

High Rise Building Vertical Alignment Survey Technology - from BIM to Field

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Teodoliten Mätteknik AB SWEDEN

Joël van Cranenbroeck, Managing Director
CGEOS - Creative Geosensing SPRL Belgium














The surveying procedures and unique Core Wall Control Survey method statement have been applied succesfully to most of top high-rise buildings and towers worldwide. CGEOS is owning the knowledge and capacity in High-Rise surveying engineering and monitoring operations and is contracted by TEODOLITEN AB Sweden for the KARLA Tower Project in Göteborg

Reaching Accuracy Requirement Challenge

- Generally speaking, accuracy requirement for construction in the past were about **± 1 cm** while nowadays pre-fab and modularity changed the rule of the game.
- In High Rise building construction, accuracy requirements are dictated by the verticality of the core walls (lift cages) and façades, cladding & glazing and tolerances are expressed in **± x mm**

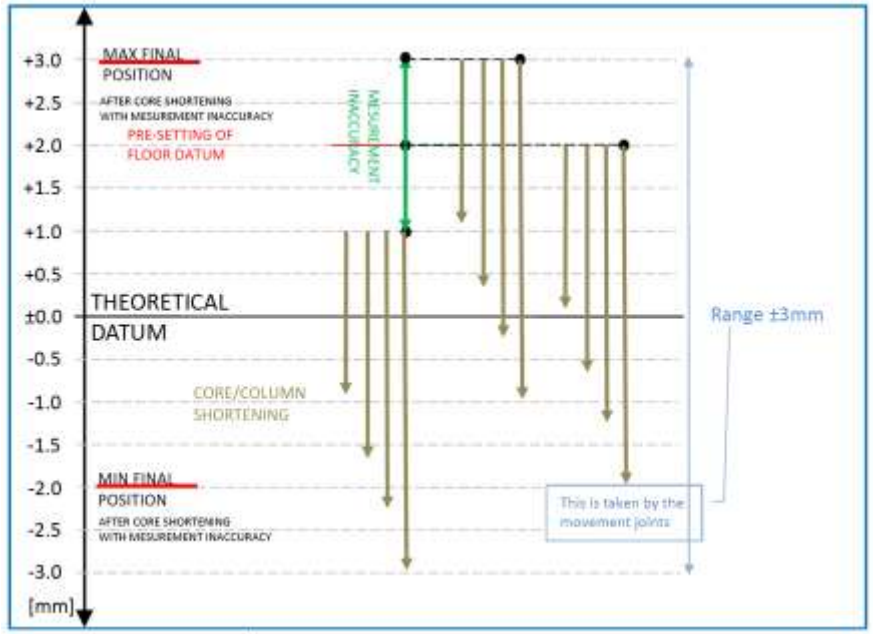
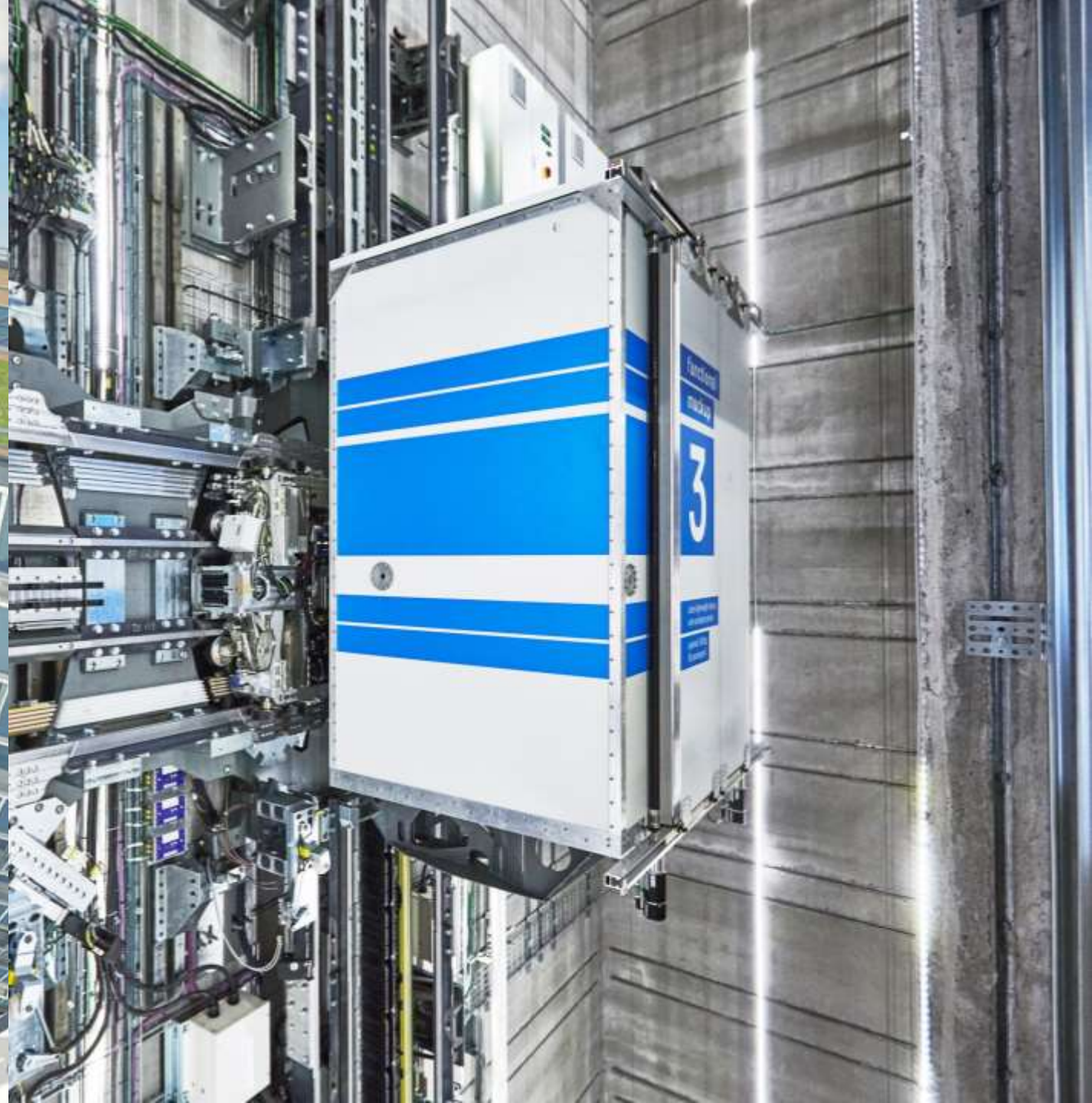


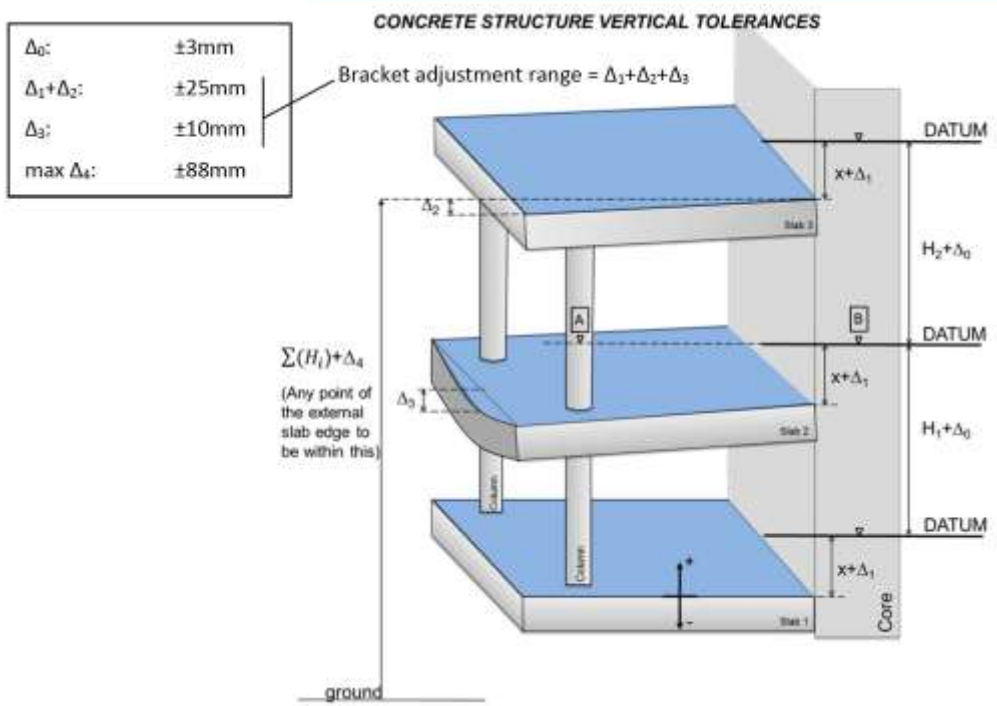
Figure 2: Concrete core tolerances Δ_0

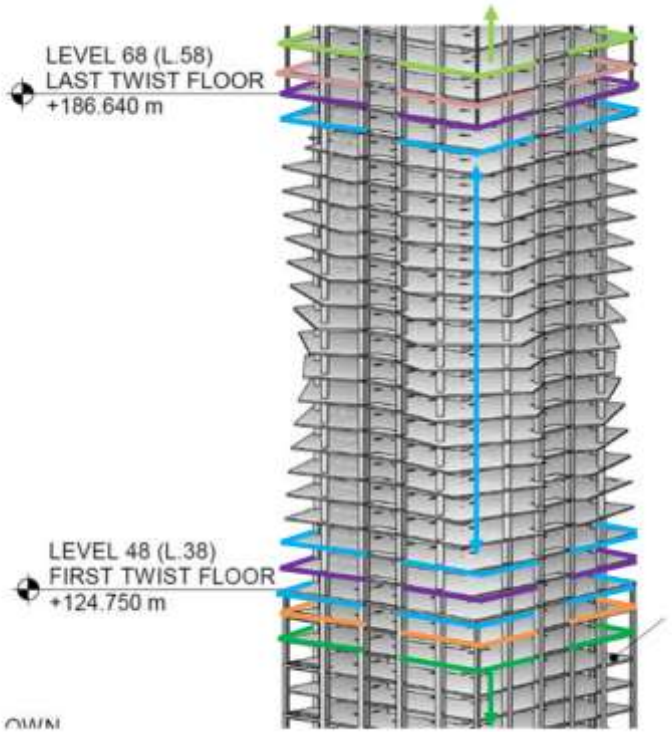
MULTI

A new era of mobility
in buildings

thyssenkrupp



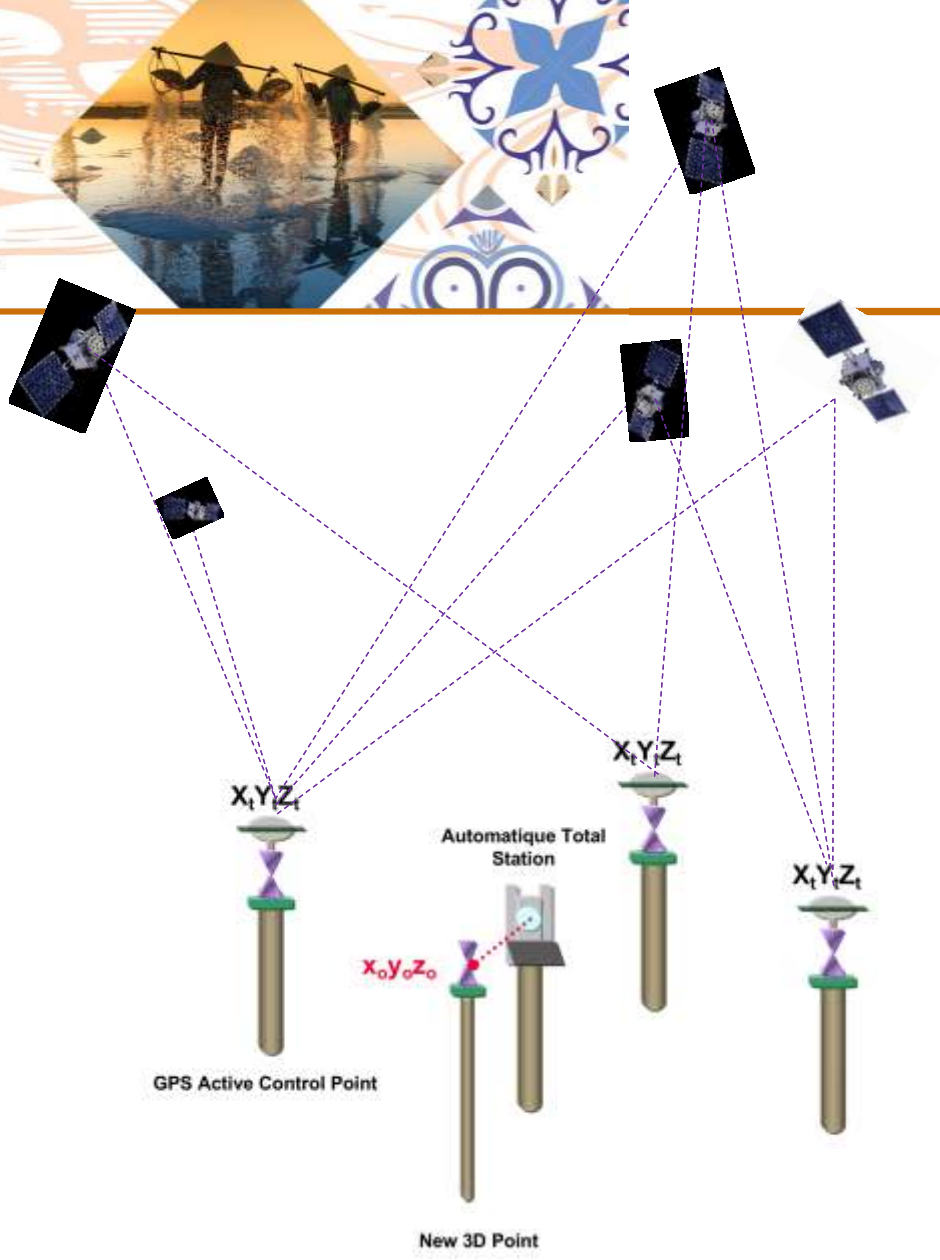




The main constraint regarding surveying accuracy performances are dictated by façades, glazing, cladding and lift shafts verticality ± 3-5 mm

High Rise Surveying Techniques Review

- 1.0 Traditional survey techniques using optical plummets and theodolites
- 2.0 Traditional surveying techniques using Total Stations and resection with laser plummets
- 3.0 **Core Wall Control Survey** method invented at first for the Burj Khalifa in Dubai


$X_tY_tZ_t$
Automatique Total Station
$X_tY_tZ_t$
$X_tY_tZ_t$
$x_oy_oz_o$
GPS Active Control Point
New 3D Point

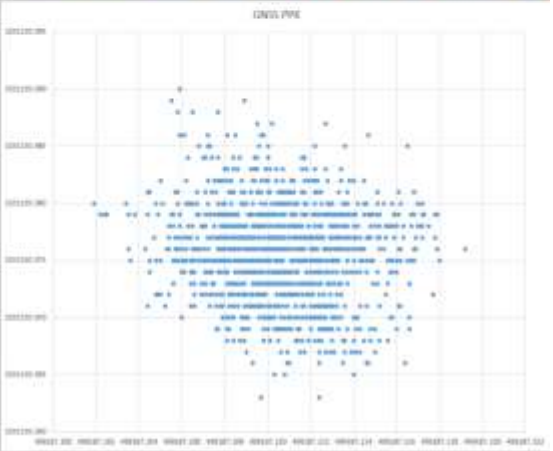
- Due to many obstruction on building top, since the Burj Khalifa we are processing the "Active GNSS control points" in PPK mode (forward & backward)
- For the Abu Dhabi Landmark tower we have been asked to process in RTK and we applied filtering techniques but ambiguities fixing process is challenging and less accurate.
- Operating in RTK requests also much attention and add-on and higher the cost without significant benefit.

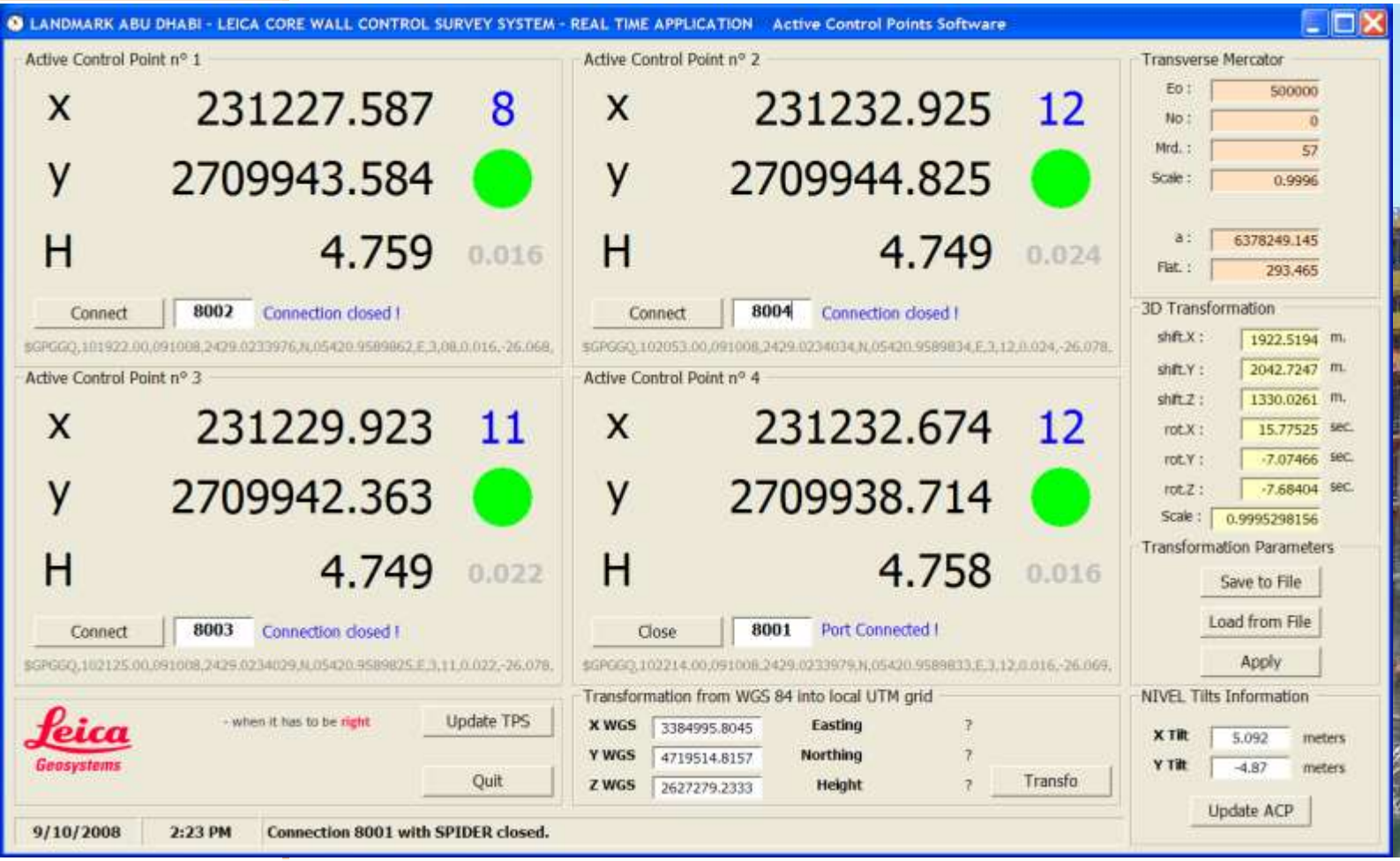
Target Residuals

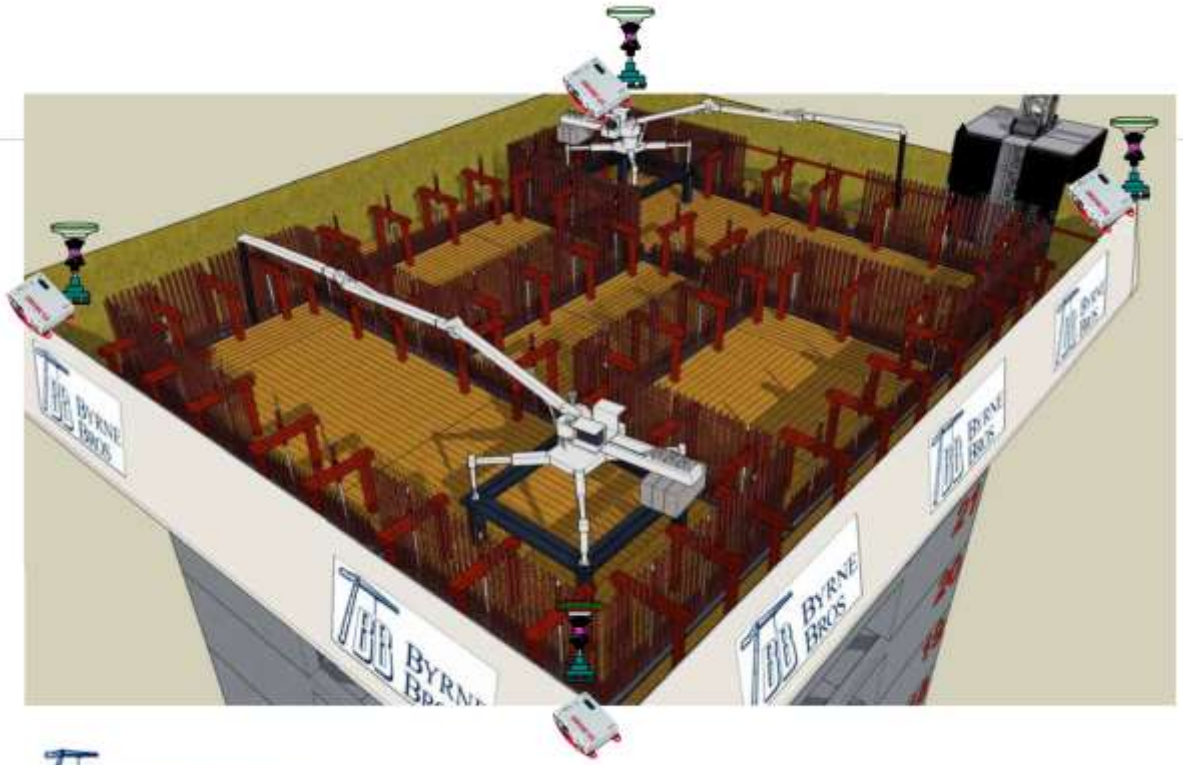
Point ID	dHz	dDist	dE	dN	dH	Use
B	0° 00' 02.9"	-0.0059 m	0.0045 m	-0.0049 m	-	2D
H	-0° 00' 04.0"	0.0003 m	-0.0027 m	0.0029 m	-	2D
3	0° 00' 55.0"	-0.0015 m	-0.0030 m	0.0015 m	-	2D
2	0° 00' 46.2"	0.0011 m	-0.0030 m	-0.0023 m	-	2D
1	-0° 00' 57.4"	0.0048 m	0.0042 m	0.0028 m	-	2D

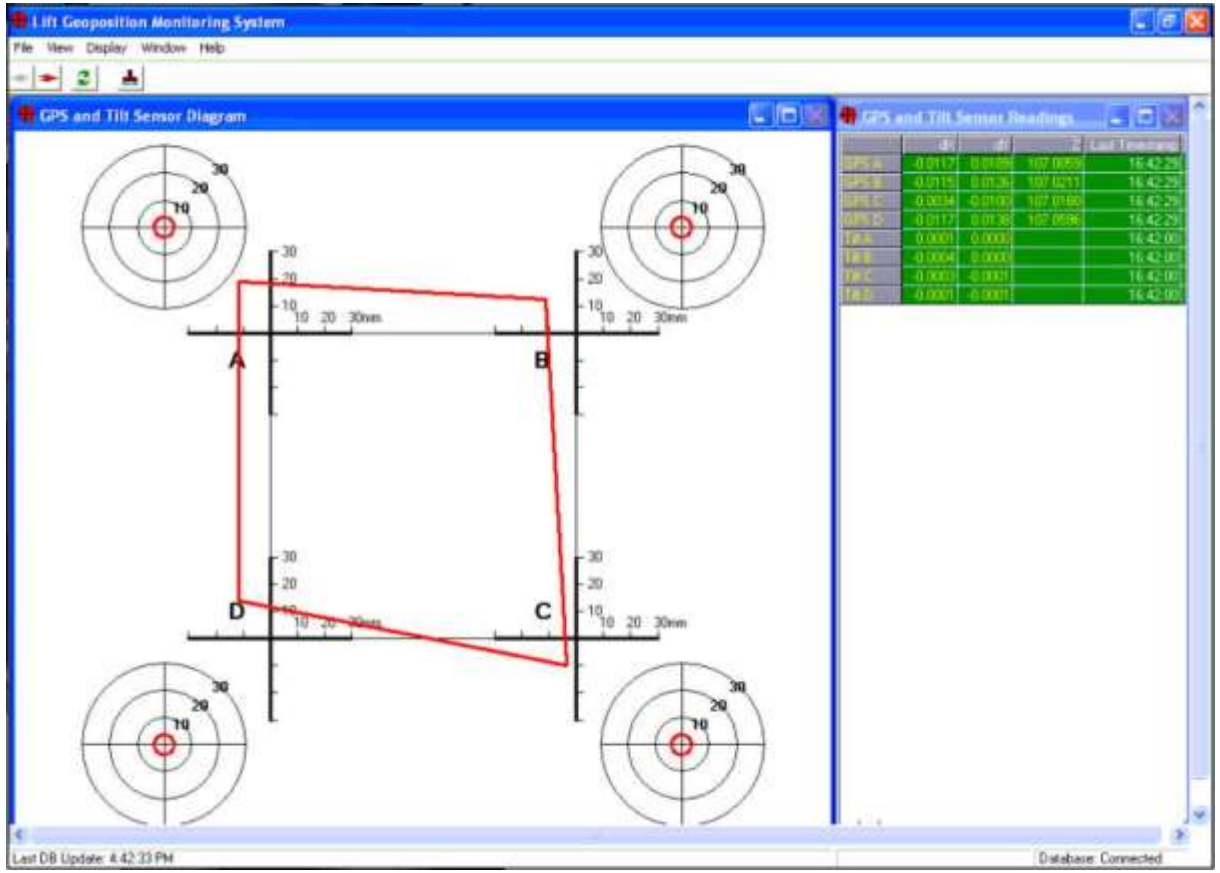
Setup Results

Station ID:	25		
Easting:	499181.6600 m	Sd. E:	0.0030 m
Northing:	3251149.4152 m	Sd. N:	0.0026 m
Height:	4.7620 m	Sd. Hgt:	0.0000 m
Use scale:	No		
Calculated scale:	-		
Orientation:	344° 52' 52.2"		
Apply scale to survey obs:	No		




LANDMARK ABU DHABI - LEICA CORE WALL CONTROL SURVEY SYSTEM - REAL TIME APPLICATION Active Control Points Software
Active Control Point n° 1
x 231227.587 8
y 2709943.584
H 4.759 0.016
Connect 8002 Connection closed !
Active Control Point n° 2
x 231232.925 12
y 2709944.825
H 4.749 0.024
Connect 8004 Connection closed !
Active Control Point n° 3
x 231229.923 11
y 2709942.363
H 4.749 0.022
Connect 8003 Connection closed !
Active Control Point n° 4
x 231232.674 12
y 2709938.714
H 4.758 0.016
Close 8001 Port Connected !
Transverse Mercator
Eo : 500000
No : 0
Mrd. : 57
Scale : 0.9996
a : 6378249.145
Flat. : 293.465
3D Transformation
shift.X : 1922.5194 m.
shift.Y : 2042.7247 m.
shift.Z : 1330.0261 m.
rot.X : 15.77525 sec.
rot.Y : -7.07466 sec.
rot.Z : -7.68404 sec.
Scale : 0.9995298156
Transformation Parameters
Save to File
Load from File
Apply
Leica Geosystems
- when it has to be right
Update TPS
Quit
Transformation from WGS 84 into local UTM grid
X WGS 3384995.8045 Easting ?
Y WGS 4719514.8157 Northing ?
Z WGS 2627279.2333 Height ?
Transfo
NIVEL Tilts Information
X Tilt 5.092 meters
Y Tilt -4.87 meters
Update ACP
9/10/2008 2:23 PM Connection 8001 with SPIDER closed.


BYRNE BROS


Lift Geoposition Monitoring System
File View Display Window Help
GPS and Tilt Sensor Diagram
GPS and Tilt Sensor Readings
A
B
C
D
Last DB Update: 4:42:33 PM
Database: Connected

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Trimble

3.0 Core Wall Control Survey

Preparation

Setup BASE station

Survey Static GNSS all primary control points

Setup TRANSFORMATION between WGS-84 and KTM coordinates

Setup

To equip the building top with 3 x GNSS receivers and antenna + 360°

Setup Total Station and perform RESECTION on Active GNSS Control Points

Adjusting formworks using reference lines and laser
NO MORE STAKE OUT after pouring

Operations

Survey “as-built” all Core Walls (lines/sections) after pouring

Compare “as-built” with CAD design and edit corrections for adjusting next formworks pull-up sequence

Survey Static GNSS all primary control points

497900 m 498000 m 498100 m 498200 m 498300 m 498400 m 498500 m 498600 m 498700 m 498800 m 498900 m 499000 m 499100 m 499200 m

3250800 m 3250700 m 3250600 m 3250500 m 3250400 m 3250300 m 3250200 m

ASSIMA (2)

Legend

Sy...	Meaning
▲	Control - 3D
▲	Control - 2D
△	Control - 1D
◎	Adjusted
▽	Reference
◎	Average
⊙	Measured
⁘	SPP
⊡	Navigated
+	Estimated

500.0 m

0.001 m 0.001 m 0.001 m 0.001 m 0.001 m

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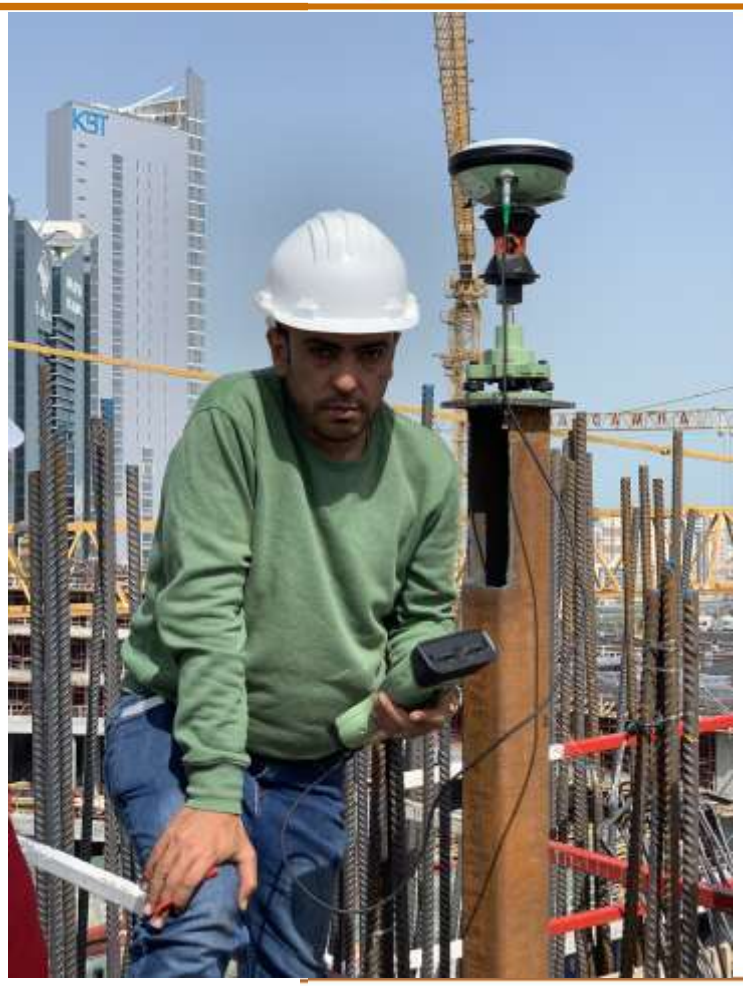

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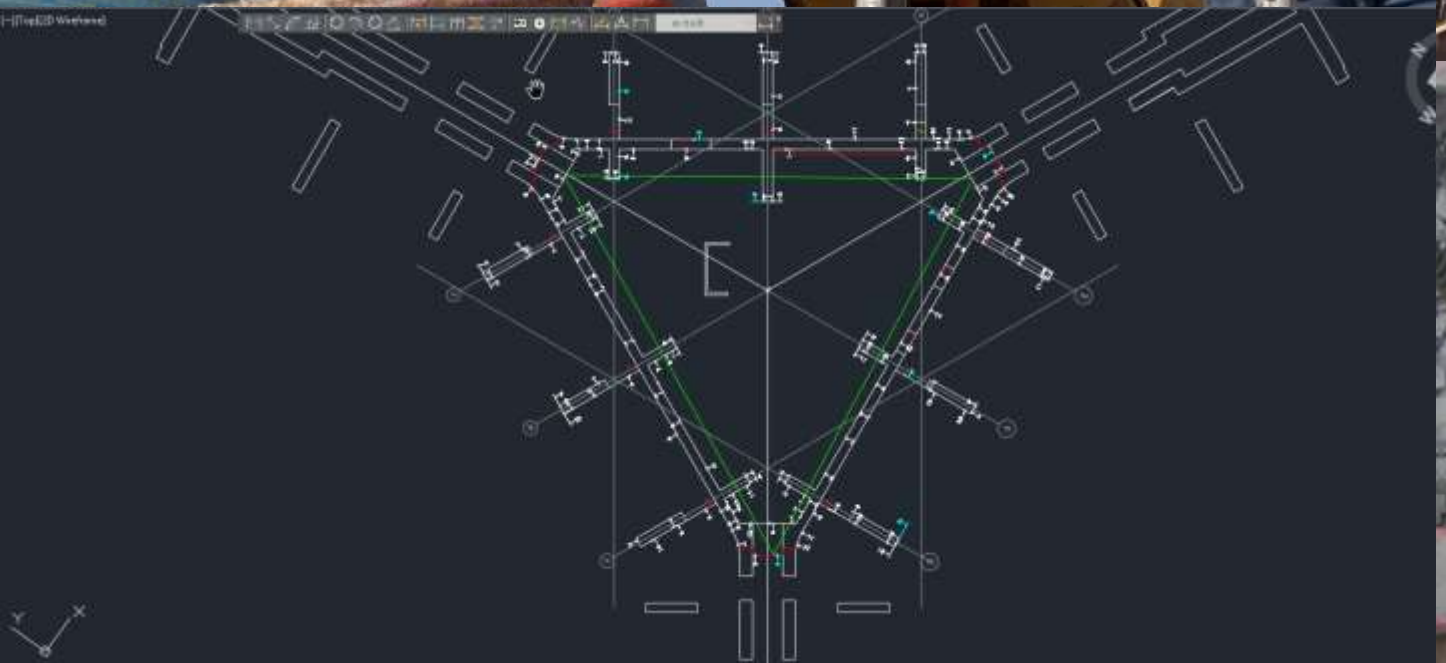
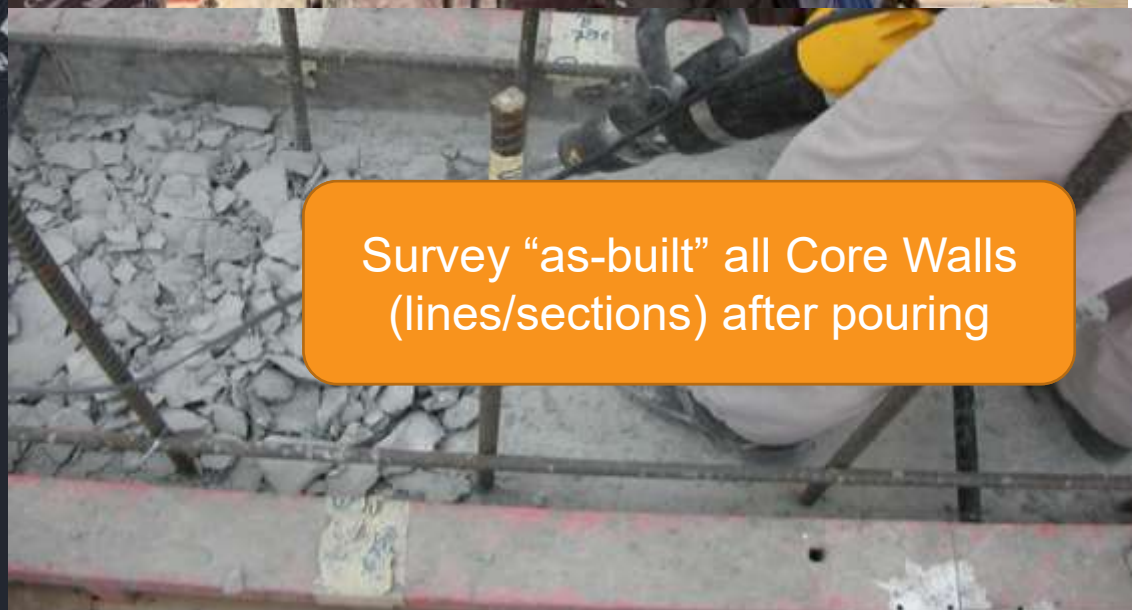
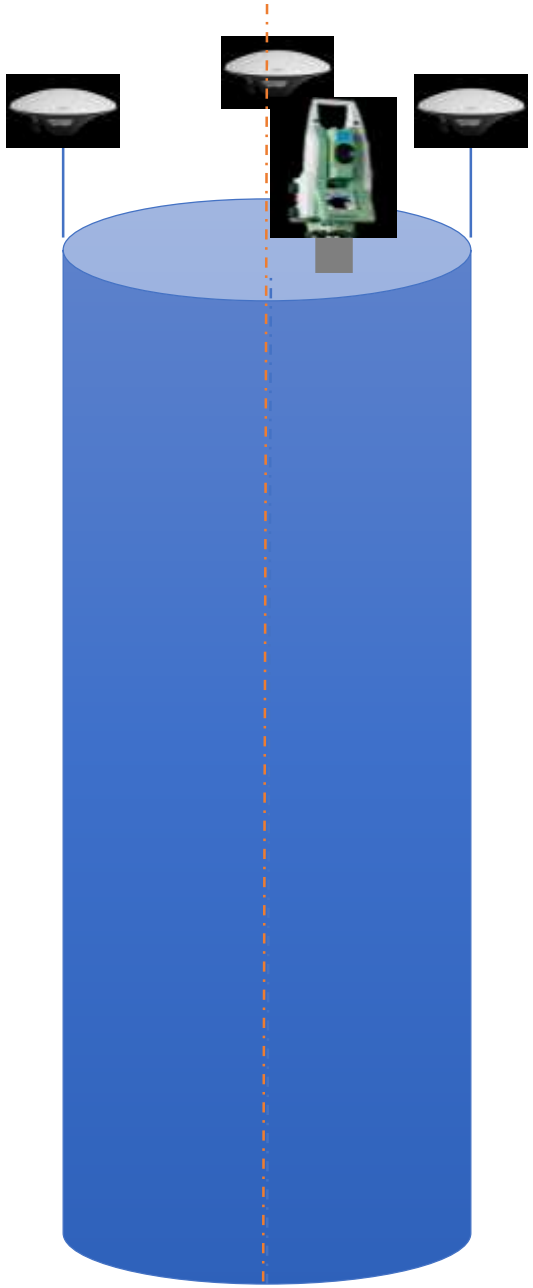




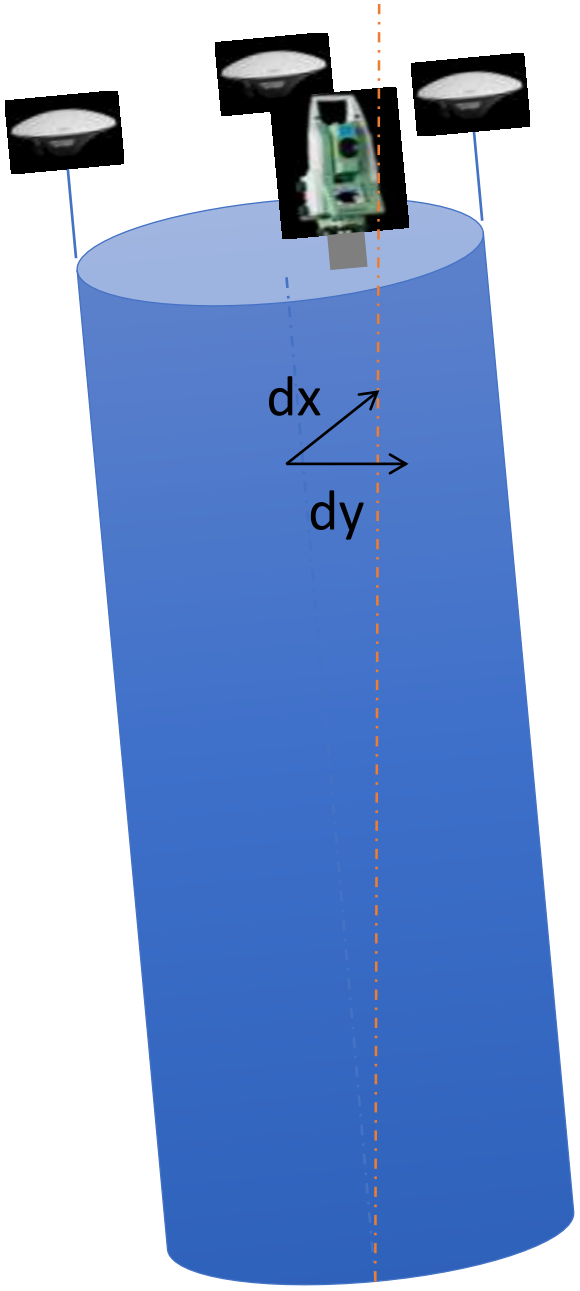
Survey “as-built” all Core Walls (lines/sections) after pouring

Adjusting formworks using reference lines and laser
NO MORE STAKE OUT after pouring



In the « aligned along the gravity vertical » no movement, the main axis of the structure coincide with the gravity vertical.

The « Active GNSS Control Points » are delivering coordinates to assist the Total Station with setting up and therefore survey and setting out elements (formworks etc, ...). The coordinates used are the coordinates provided by the designer.

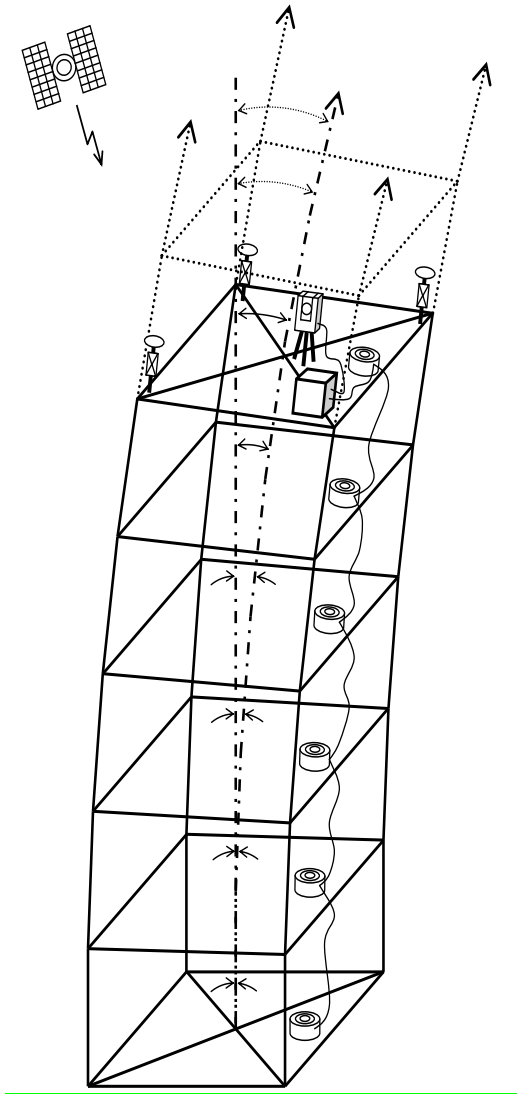


Due to various loads (sun insolation, cranes loads, wind ...) the main axis of the structure doesn't coincide with the gravity vertical.

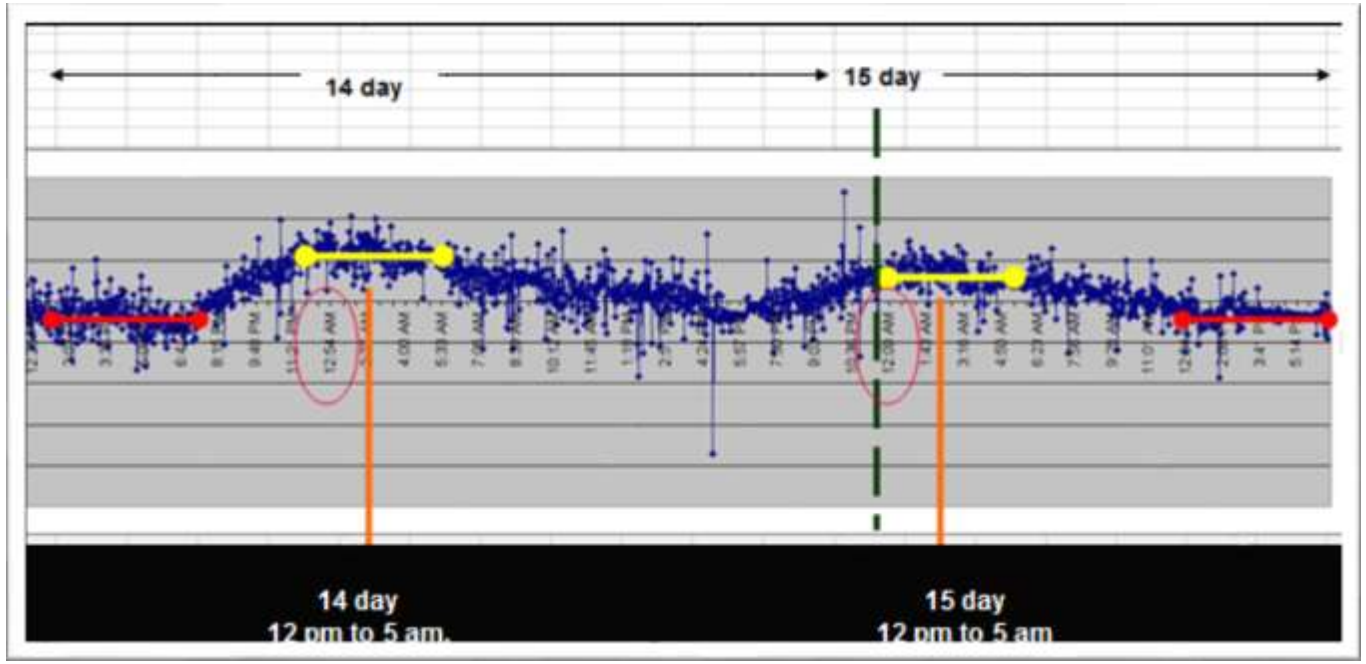
The « Active GNSS Control Points » are delivering coordinates to assist the Total Station with setting up AT THE PRESENT PLACE (that is offset from the design coordinates)

To keep building, we do need to TRANSLATE the design coordinates at the PRESENT PLACE. This is where we do need PRECISE DUAL AXIS INCLINOMETERS that will give us the deflection DX, DY of the structure MAIN AXIS vs GRAVITY

Real Time Monitoring - Building Tilt



It shall drive new parameters to evaluate the current building condition with high frequency and statistical approach to analyse the structure.



High Rise Surveying Techniques Review

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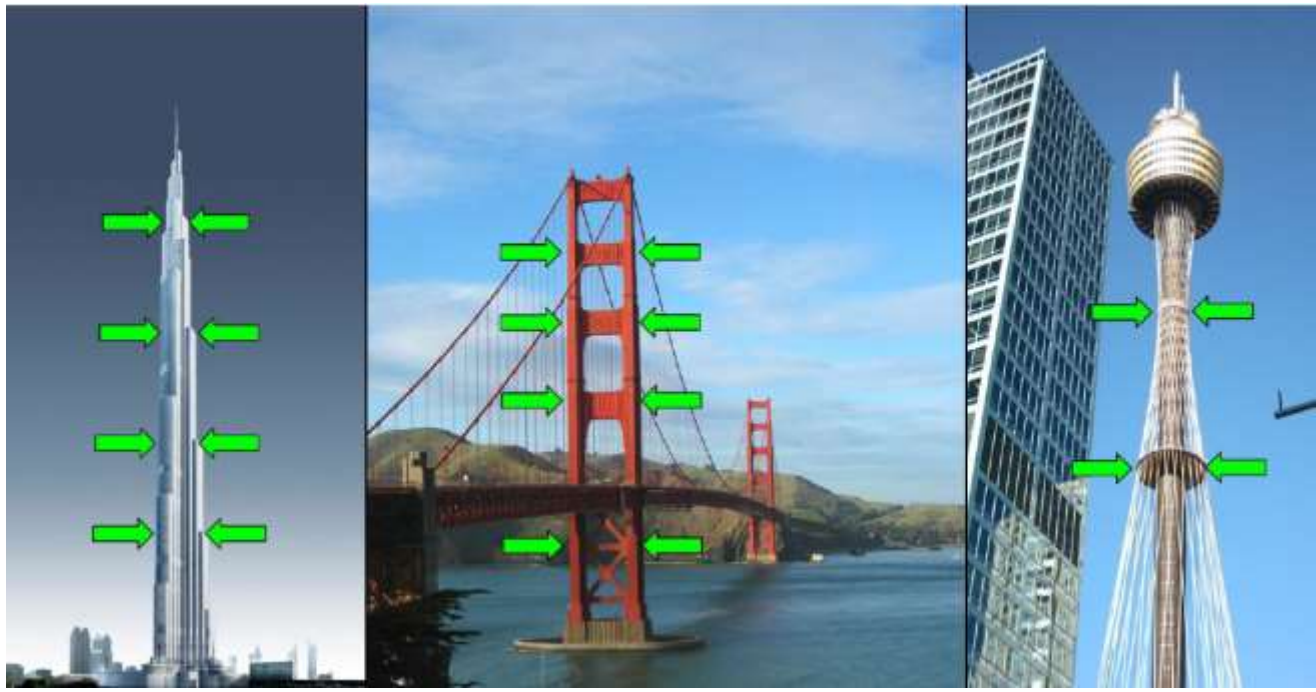
- 3.5 Technology improvements, new request and new solutions

GNSS

- GNSS (only GPS at the Burj Khalifa Dubai) +GLONASS +GALILEO +BEIDOU = ± 25 SV's
- Cost reduction in GNSS receivers and antennas
- Open Source software such RTK-LIB for double checking

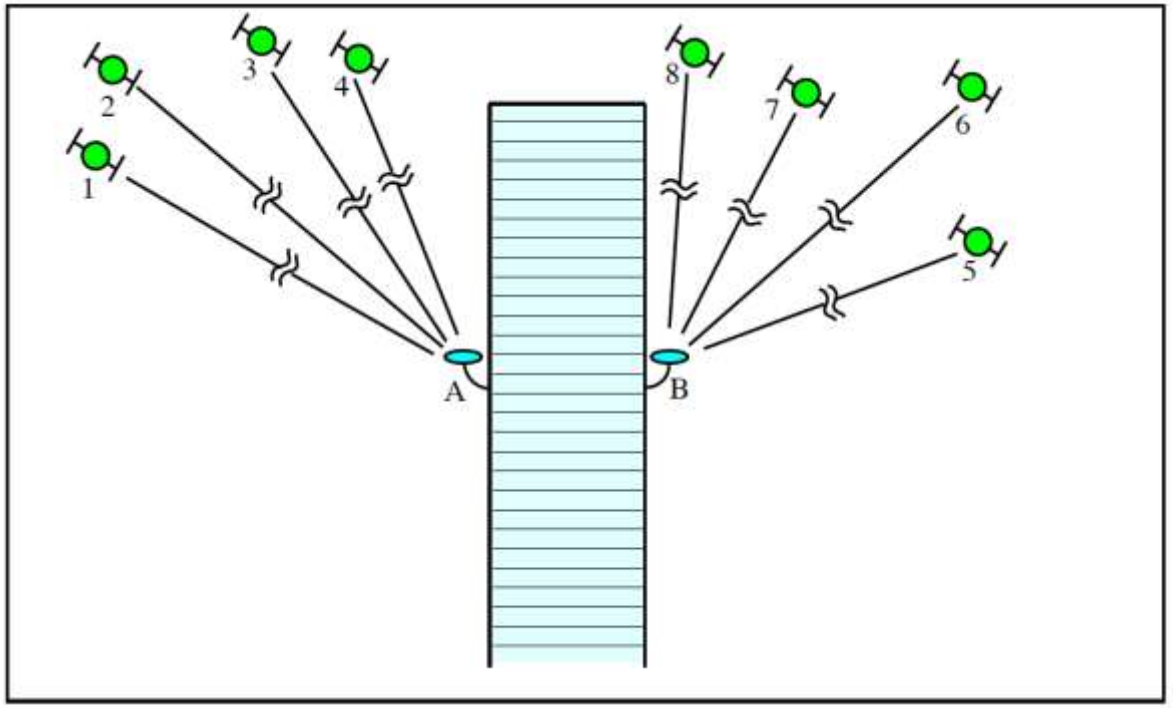
The GNSS Mid Height Problem

- We have been asked to suggest a proposal for monitoring by GNSS the Taipei 101 but without setting up a GNSS antenna on the building top !
- Our idea was to surround building upper part with several GNSS antenna's like used for missile guidance …



The GNSS Mid Height Problem

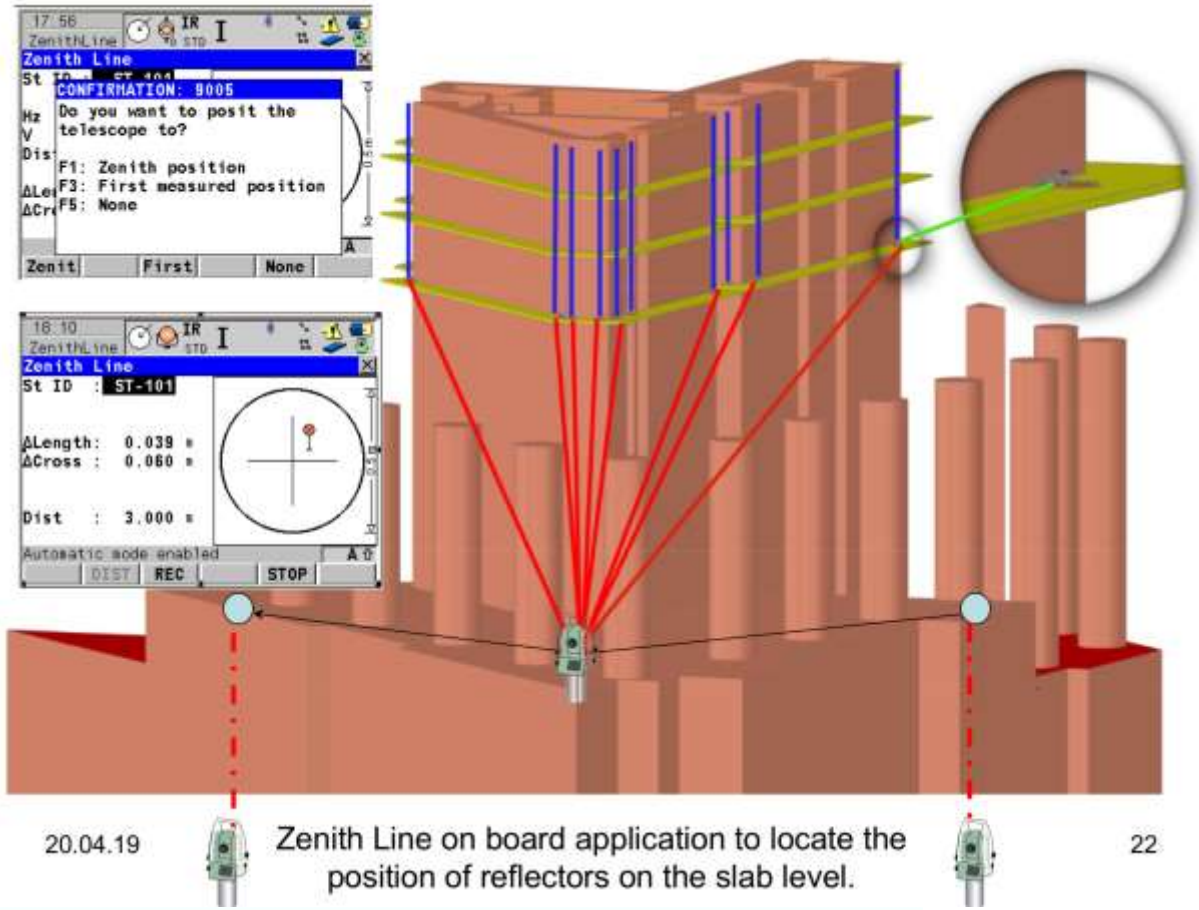
- There are several approaches :
  - Either to connect all GNSS antenna's to a single receiver to benefit of a single oscillator (like GNSS 2 x antenna's direction)
  - Consider separated GNSS receivers and antenna's and use OCXO external oscillator to drive the GNSS receiver's clocks.
- Solution is about translation (Virtual Monitoring Point = VMP)



Zenith Line Application

- Instead of using vertical optical or/and laser plummet, we develop the application to use a Total Station + Automatic Target Recognition to track vertical deflection automatically.
- original idea 1995 © Joël vC

- When there is no possibility to use "Active GNSS control Points"
- To have inside vertical control
- Can be applied in any reference line as originally invented for bride monitoring



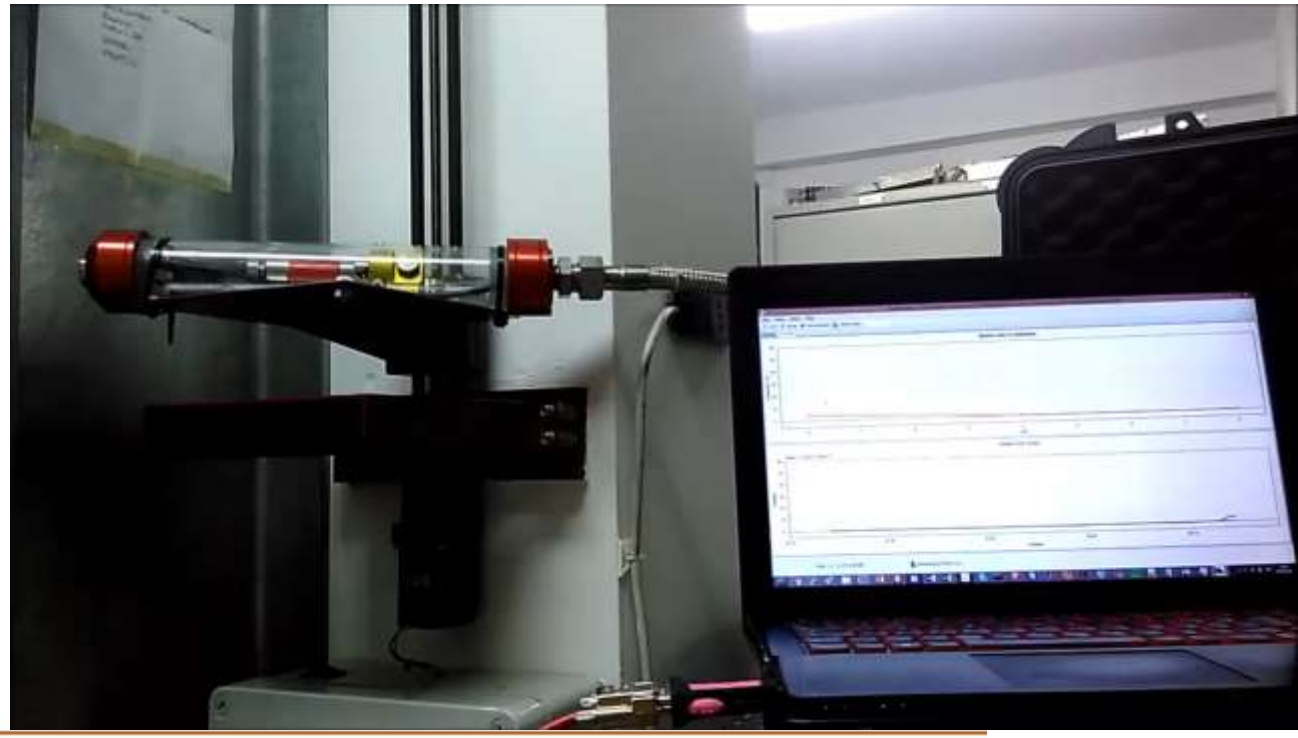
20.04.19 Zenith Line on board application to locate the position of reflectors on the slab level. 22

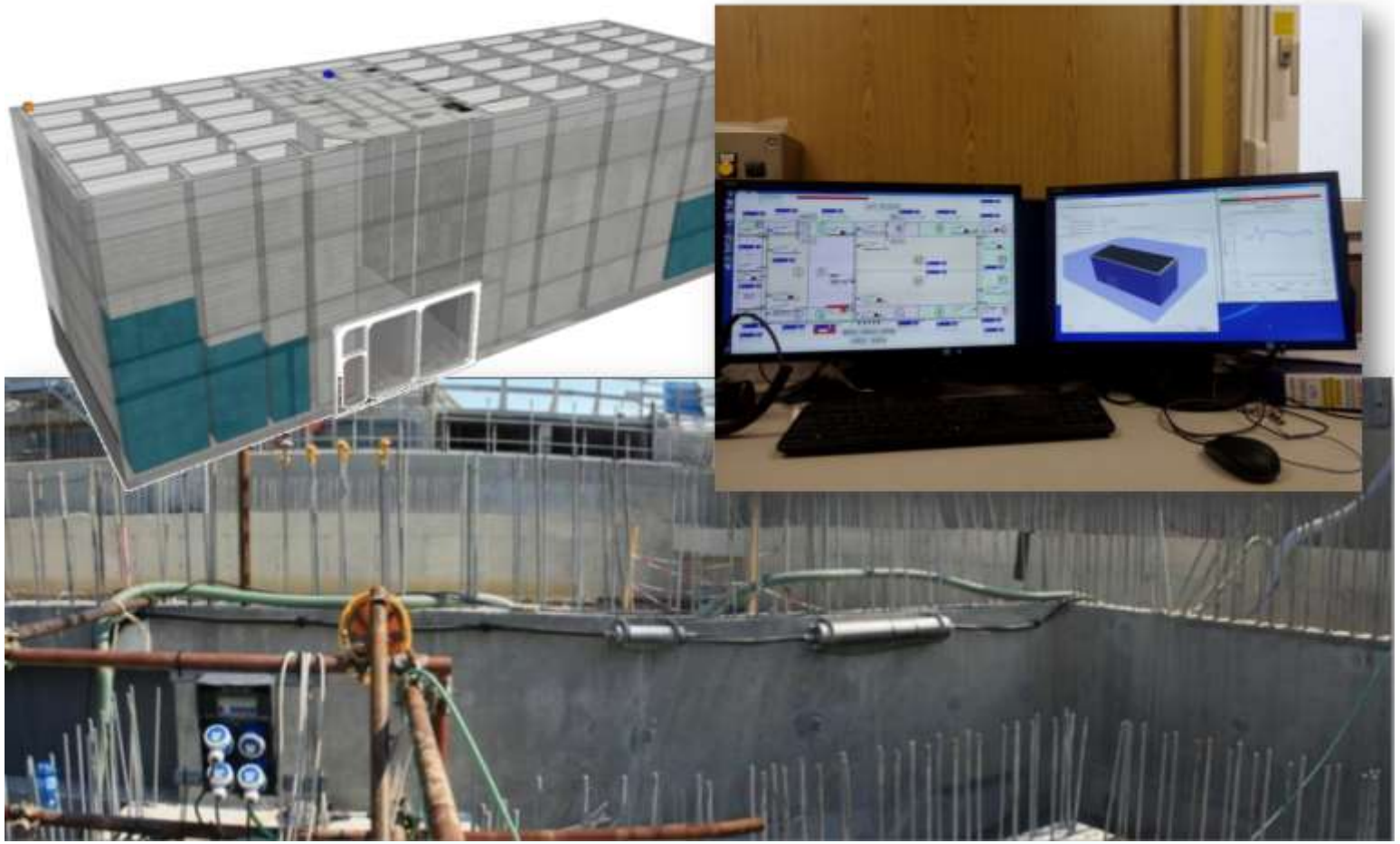
New Instrument to Evaluate …

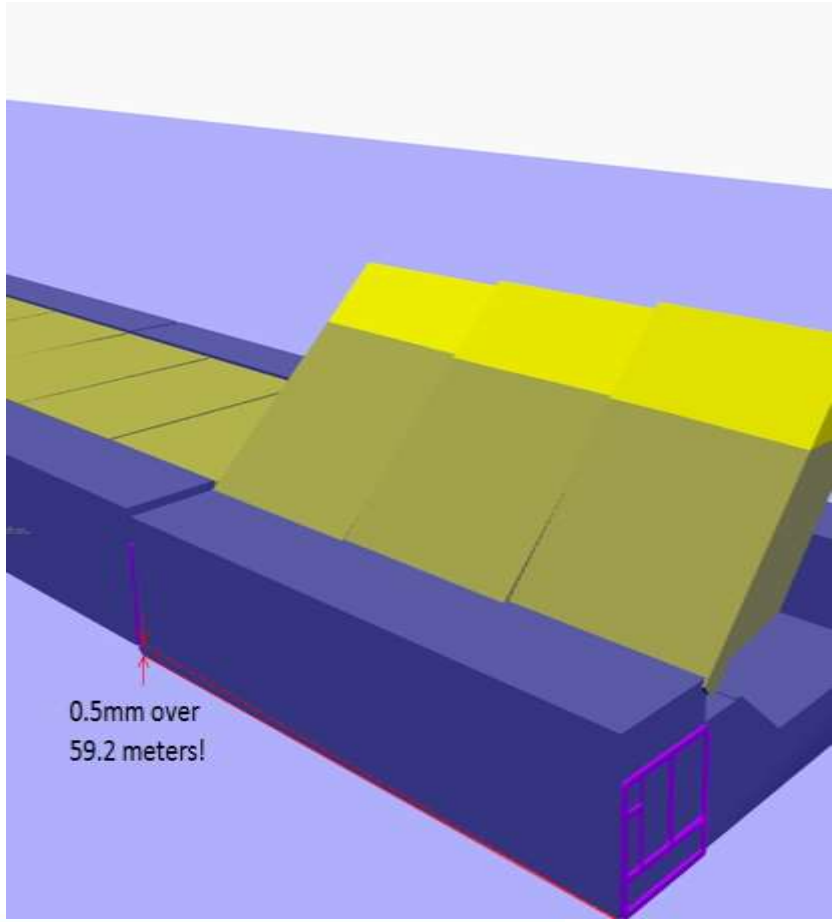
- TOPCON GTL-1000 – a compact scanner integrated with a fully featured robotic total station, enabling a site engineer to complete a layout and scan on a single set-up.
- The Topcon GTL1000 which unlike scanning total stations such as the Leica MS60 and Trimble SX10 is a conventional total station with scanner plonked on top.

Automatic Levelling System by AGISCO srl MI

- AGISCO srl Milano has invented, designed and is producing an Automatic Levelling System (Profilometer) based on pressure gauge
- Accuracy on level of ± 0,1 mm
- Ideal for basement and foundations monitoring
- 24 hours / 7 days

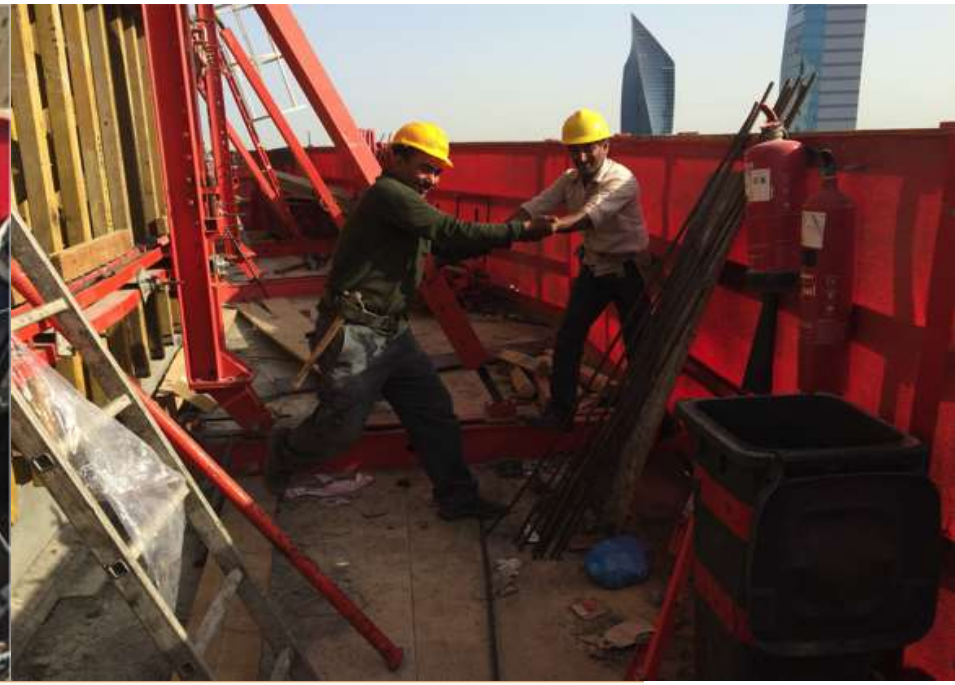




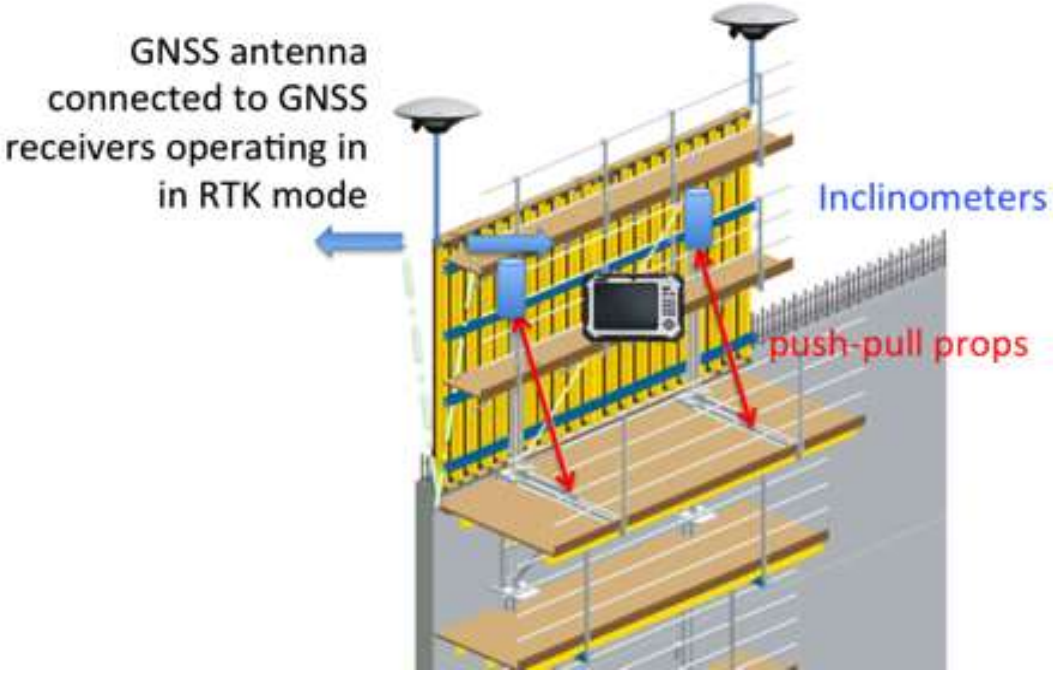

0.5mm over
59.2 meters!

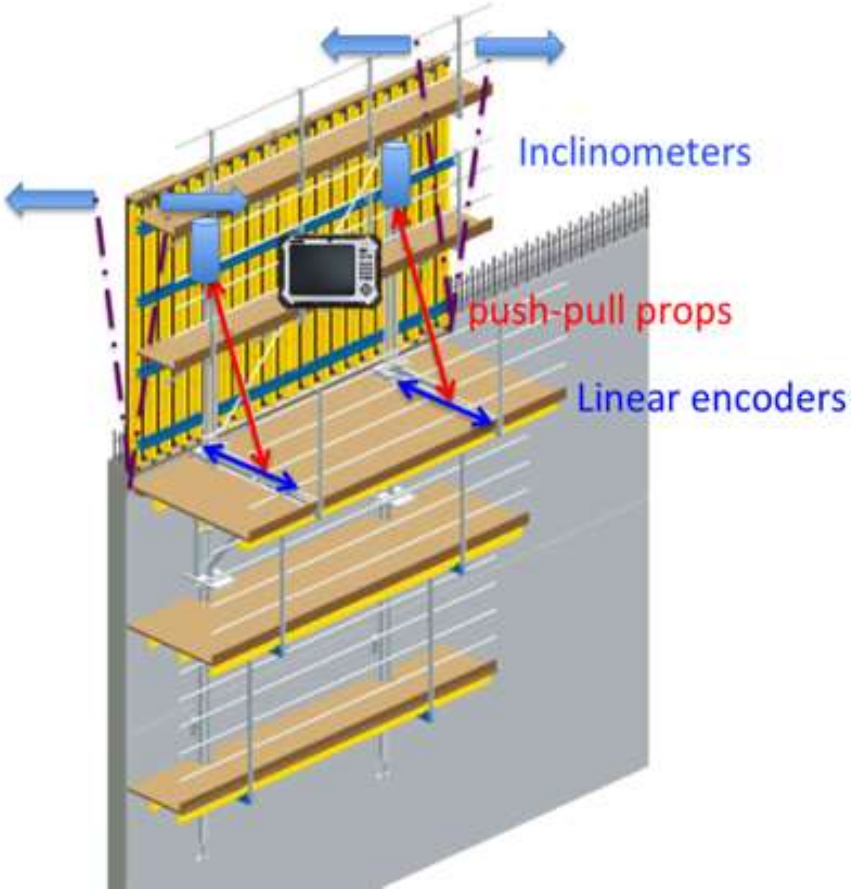
Semi-automatic Setup Formwork System

- The only way is to adjust the top part of the formwork is to modify its inclination.
- It's still a hard work process based on push-pull prop ...



Semi-automatic Formwork



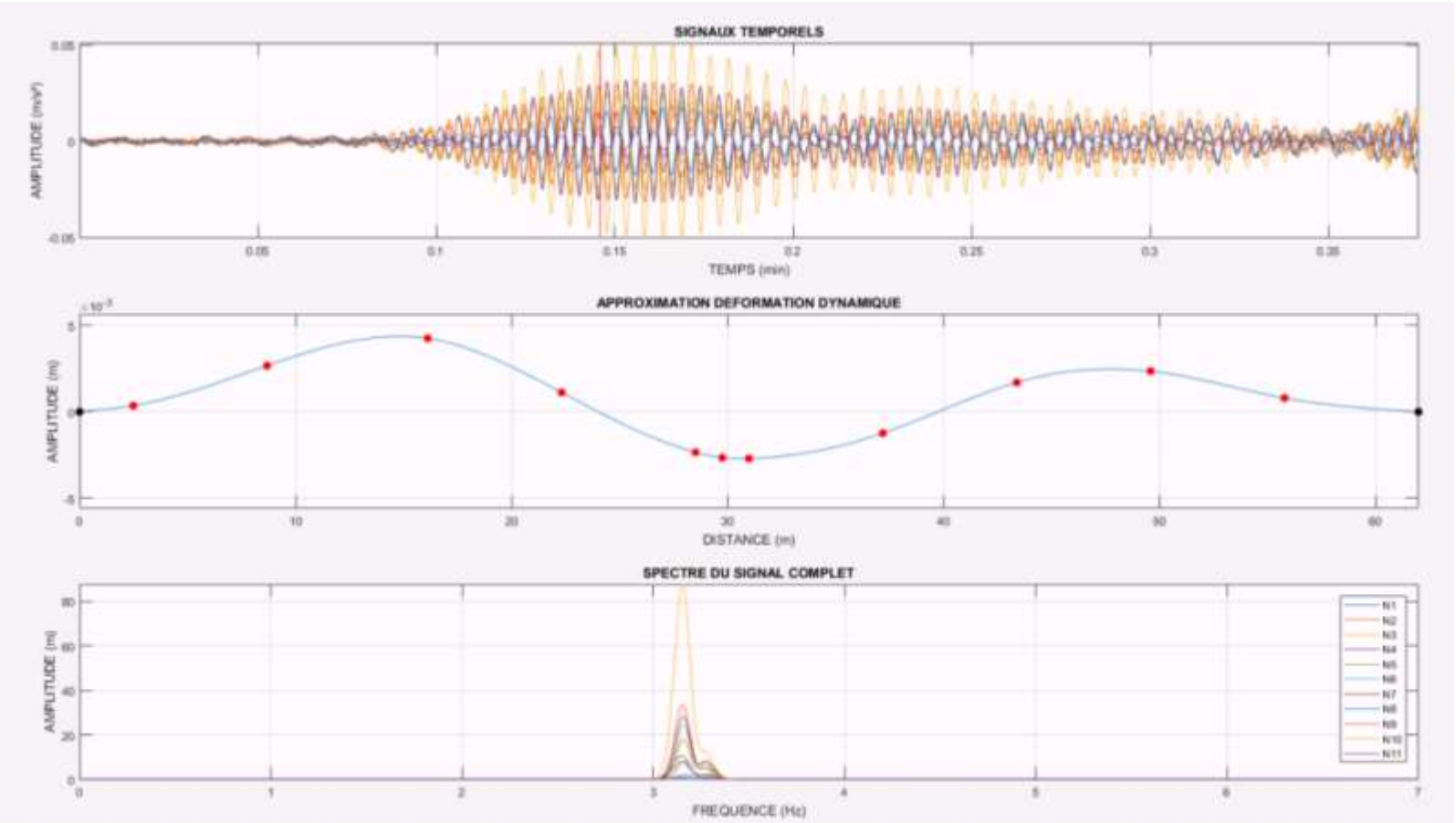


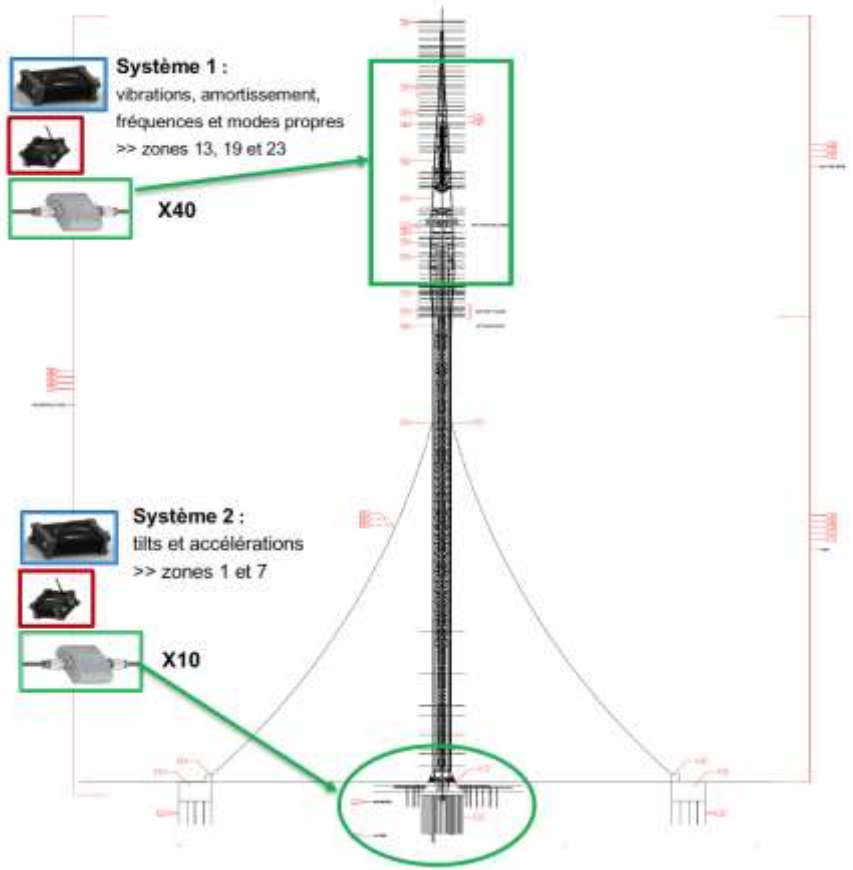
UAV for High Rise construction

- Companies like Liebherr, the world's largest manufacturer of tower cranes, recognize the need to adopt intelligent and collaborative system to improve project management efficiency.
- A camera mounted on a crane is an excellent alternative to drone mapping and traditional techniques such as terrestrial laser scanning.

Frequency & Operational Modal Analysis

- **Morphosense** was created in 2016. It originates from the Systems department of CEA Leti.
- The technology is based on a network of high precision MEMS accelerometers with patented algorithms which estimate the 3D deformation and vibrations of infrastructures and superstructures.


SIGNAUX TEMPORELS
AMPLITUDE (mV²)
TEMPS (min)
APPROXIMATION DEFORMATION DYNAMIQUE
AMPLITUDE (m)
DISTANCE (m)
SPECTRE DU SIGNAL COMPLET
AMPLITUDE (m)
FREQUENCE (Hz)


Système 1 :
vibrations, amortissement,
fréquences et modes propres
>> zones 13, 19 et 23
X40
Système 2 :
tilts et accélérations
>> zones 1 et 7
X10

High Rise Surveying Techniques Review

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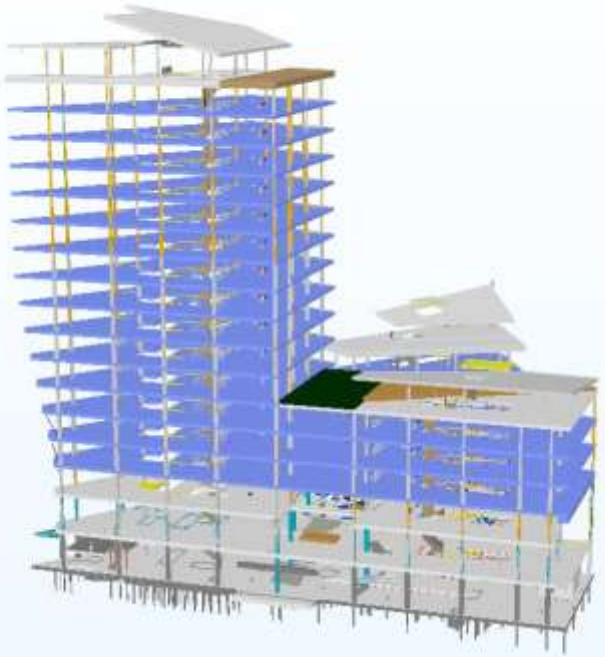
- 3.0 **Core Wall Control Survey** method invented at first for the Burj Khalifa in Dubai
- 3.5 Technology improvements, new request and new solutions
- 4.0 Integrated technologies (surveying & monitoring) based on BIM

Integrated Technologies - Information Technology - BIM

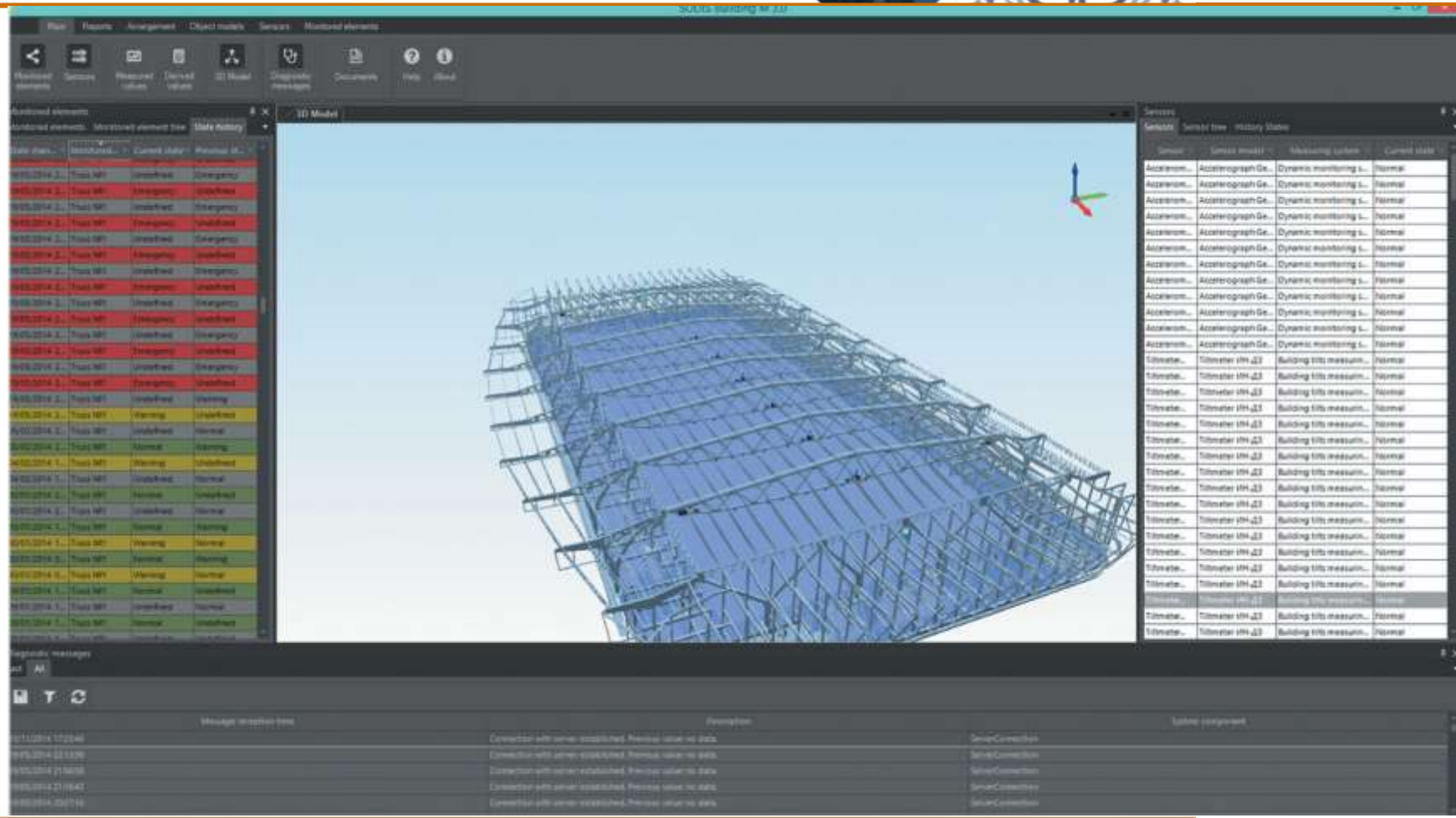
- All the instruments and sensors are producing big data that are becoming more and more difficult to handled and to confront with the documentation design.
- BIM is progressively used in high rise construction (National Bank of Kuwait New Tower) because such infrastructures are de facto complex and unique with challenging design
- Clashes detection is often cited as one of the major benefit while the counter part is significant investment in IT and operators.
- We are foreseeing a huge interest for gathering surveying and monitoring data in real time

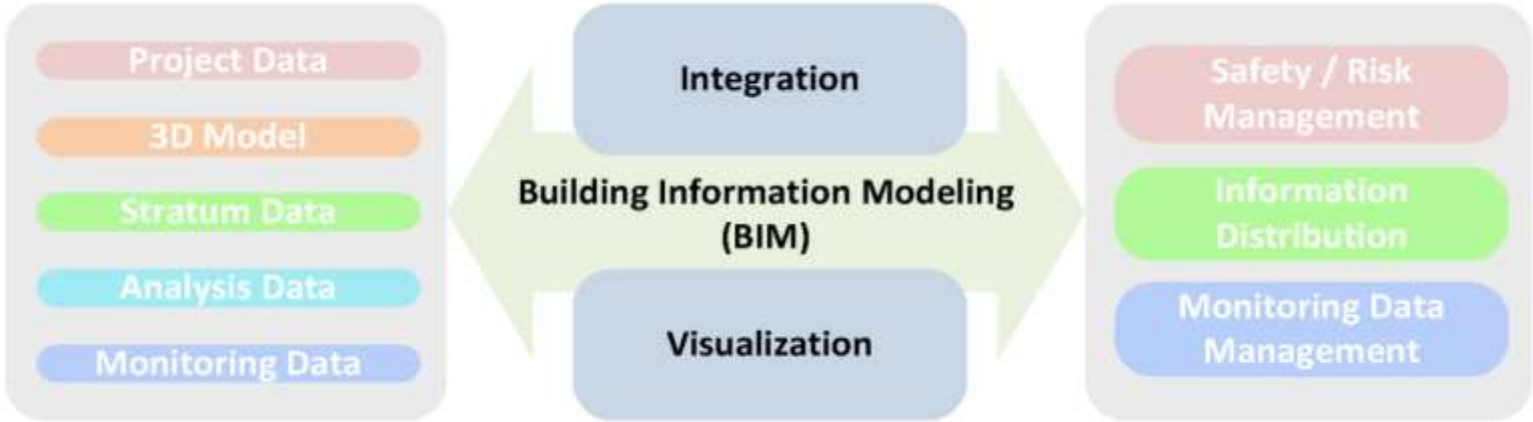
BIM Surveying - TEODOLITEN AB Sweden

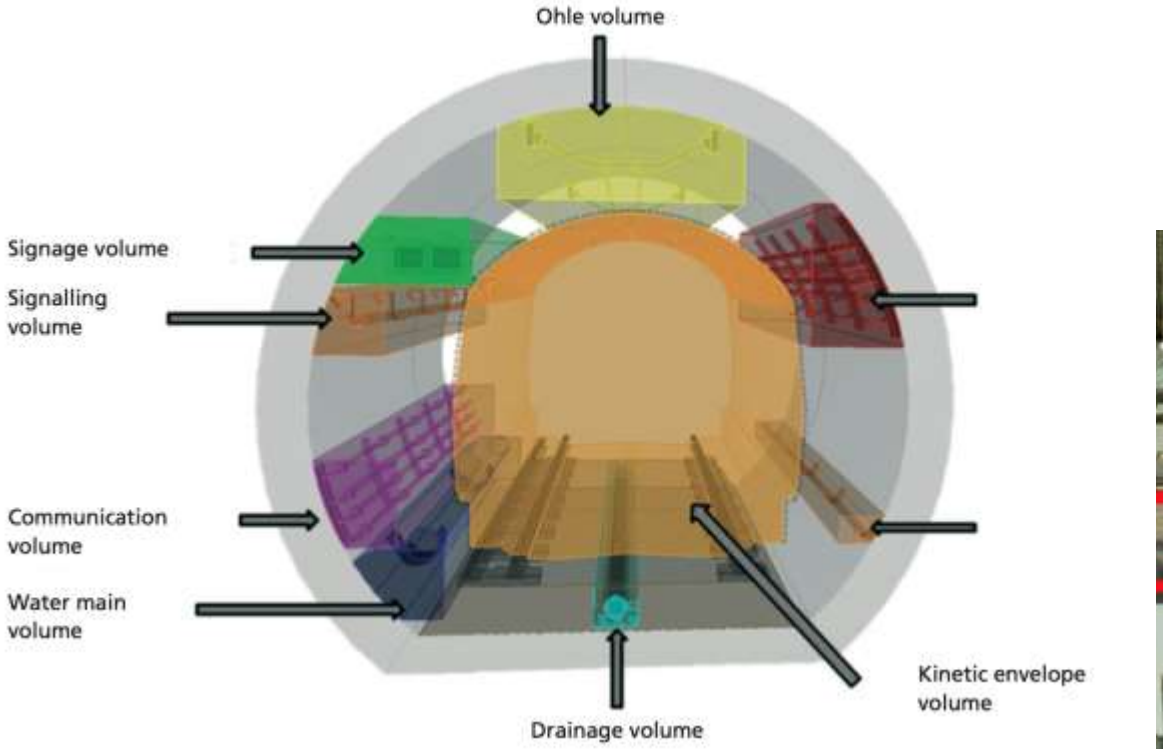
- TEODOLITEN AB is using BIM since many years to handle surveying project in drawing less mode
- They developed unique expertises to interact from BIM to field and vice versa
- On the field, surveyors are connected to Internet Mobile to exchange 3D structured data in real time.



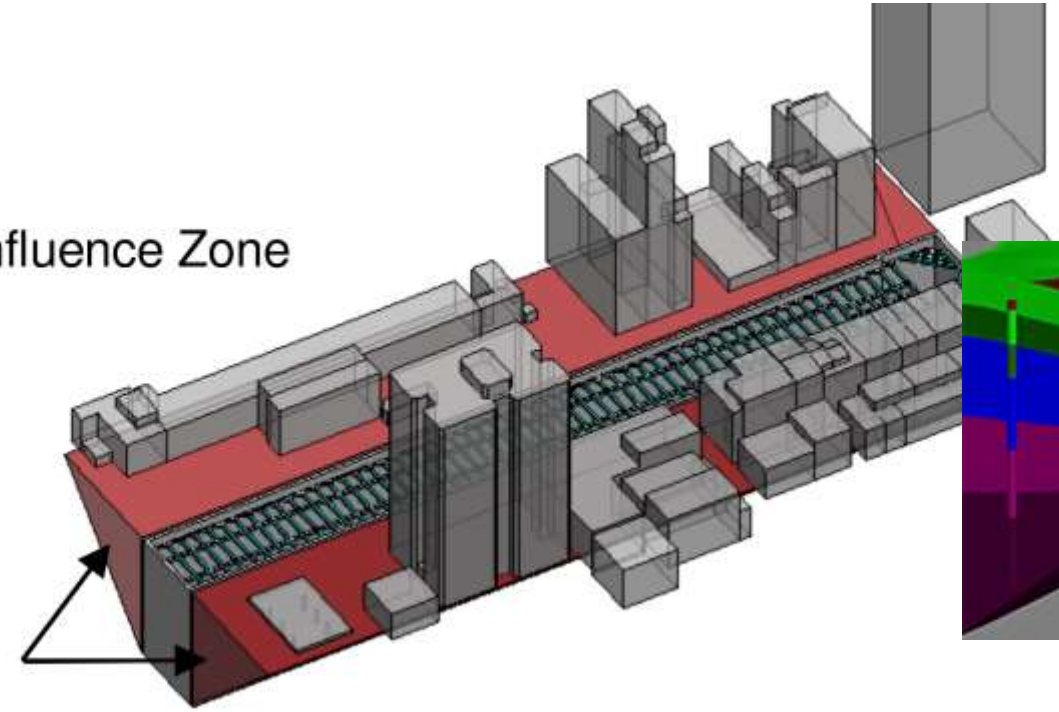
- Developed by SODIS, a Russian company involved in buildings monitoring systems development.
- The approach is to combine into a CAD/BIM environment, sensory data for subsequent structural analysis

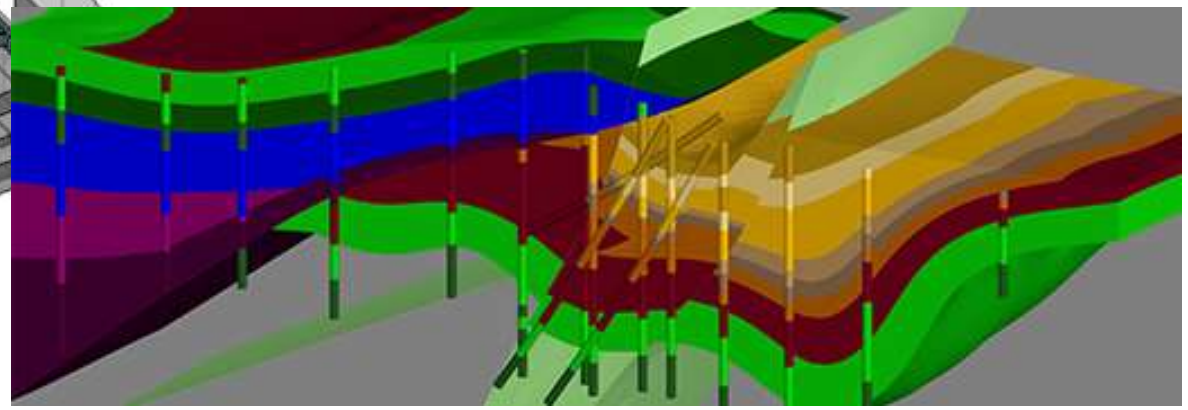


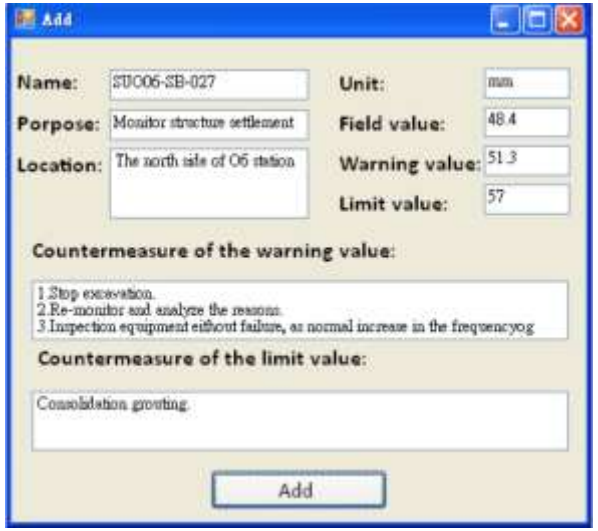

Project Data
3D Model
Stratum Data
Analysis Data
Monitoring Data
Integration
Building Information Modeling (BIM)
Visualization
Safety / Risk Management
Information Distribution
Monitoring Data Management

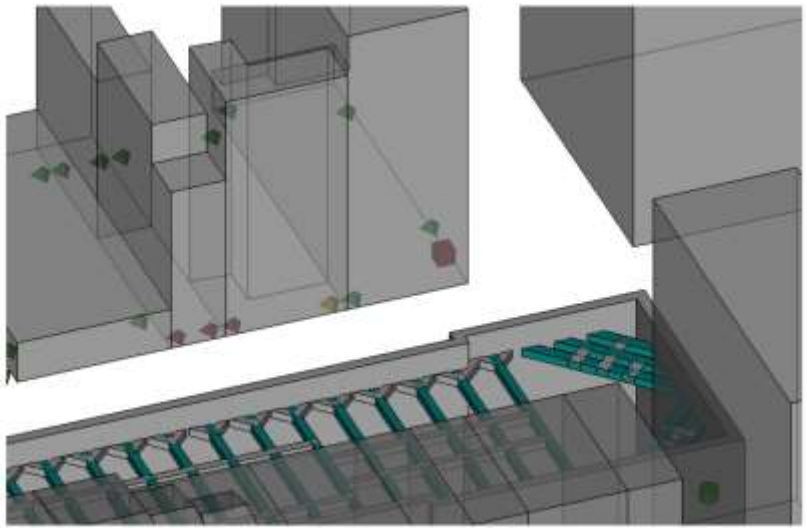

Ohle volume
Signage volume
Signalling volume
Communication volume
Water main volume
Kinetic envelope volume
Drainage volume

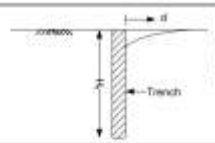
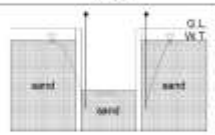
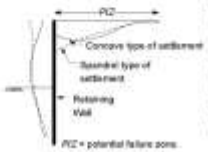
Influence Zone









Construction Stage	Diagram	Environmental Impacts	Monitoring Data	Influence Zone
Retaining Wall Construction		Pile-driving induced ground shock leads to cracking in adjacent structures and settlement.	1. Building Settlement Point (SB) 2. Settlement Point (SM) 3. Tiltmeter Point (TI)	d=0.5H_t Where H_t is the depth of a trench)[3]
Groundwater Pumping		Pumping causes lowering of ground water table which increases the effective stress on soft clay and results in consolidation settlement.	1. Settlement Point (SM) 2. Standpipe Piezometer (PS)	$Q=\frac{2\pi k D(s_1-s_2)}{\ln(r_2/r_1)}$ Q=Discharge Quantity by Theis(1935)[3]
Excavation		Excavation causes excessive wall deflections which may then induce adverse movements to adjacent foundations, leading to large surface settlement, and cracking of pavements.	1. Building Settlement Point (SB) 2. Settlement Point (SM) 3. Tiltmeter Point (TI)	PIZ_1=min ($2H_t$, H_s) H_t=The excavation depth and H_s=The depth of the hard soil. PIZ_2=min(2H_t,B) H_t = the depth of the soft clay bottom and B = The excavation width. PIZ=max(PIZ_1, PIZ_2)[3]

Conclusion

- Starting our journey in 2006 with the construction of the Burj Khalifa and the invention of the Core Wall Control Survey method, we keep developing and improving Surveying Engineering solutions for High Rise structures.
- More sensors and instrumentation are now included in our proposal. Structural analysis software, post-construction monitoring and data management with BIM are paving the way to new developments.
- High rises with unique design are keeping challenging the construction business and the surveyors must definitively take part of that outstanding human adventure toward the limitless sky. **They have therefore to accept the challenges, innovate, breaking rules and keep learning.**

Joel van Cranenbroeck
Collaborateur Scientifique at UCLouvain ICTE...
2w

Back to Core Wall Control Survey method that I invented at first for the Burj Khalifa tower in Dubai 10 years ago together with the "Active GNSS Control Point" ! We keep improving and developing that approach that will be presented at the FIG Working Week at Hanoï soon.

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Thank you very much for your attention

Cảm ơn bạn rất nhiều sự chú ý của bạn

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