

# TERRESTRIAL LASER SCANNER FOR SURVEYING AND MONITORING MIDDLE AGE TOWERS

Eleonora BERTACCHINI, Emanuele BONI, Alessandro CAPRA,  
Cristina CASTAGNETTI, Marco DUBBINI, Italy



Laboratory of Geomatics  
Dept. of Mechanical and Civil Engineering  
University of Modena and Reggio Emilia



XXIV FIG International Congress 2010 - 11-16 April, Sidney, Australia  
Session TS 4D - TLS applications I -paper n.4445

## Introduction

TLS surveying for 3D model resitition and for geometrical determination of the structures

Surveying and data processing methods in order to:

- define the **height of the towers** with respect to the gorund or, if possible, with respect to a benchmark of known height;
- determine the **overhang** of the towers and the direction of greatest vertical deviation;
- analyze the planimetric ad altymetric **trajectory of geometrical barycenter** versus the height variation
- enhance the **diagnostic** approach of TLS 3D surveying

Scan Station 2 model of Leica was used.

Size sampling of 8 mm was used from each scan station

## Middle age towers surveyed



This survey deals , respectively, with the towers: **“Della Sagra” (Carpi)**  
**Ghirlandina (Modena)** and **Asinelli (Bologna)**.

All these towers, dating back to the 12th century and built in brickwork, are examples of the North-Italian Romanesque style.

Some differences also exist among them, such as the way they were built, their height, the foundation type and the following modifications.

## Survey planning

Different scan image stations (Asinelli Tower)



The survey is composed by several laser scanner sequences; in consideration of tower heights, it was necessary even using scan positions at different height above ground surface ( green arrows) in order to avoid an inclination angle too much relevant.

## Target installation

A minimum number of three targets were put on each image for the alignment of cloud points

Targets were located on the towers and on closest buildings



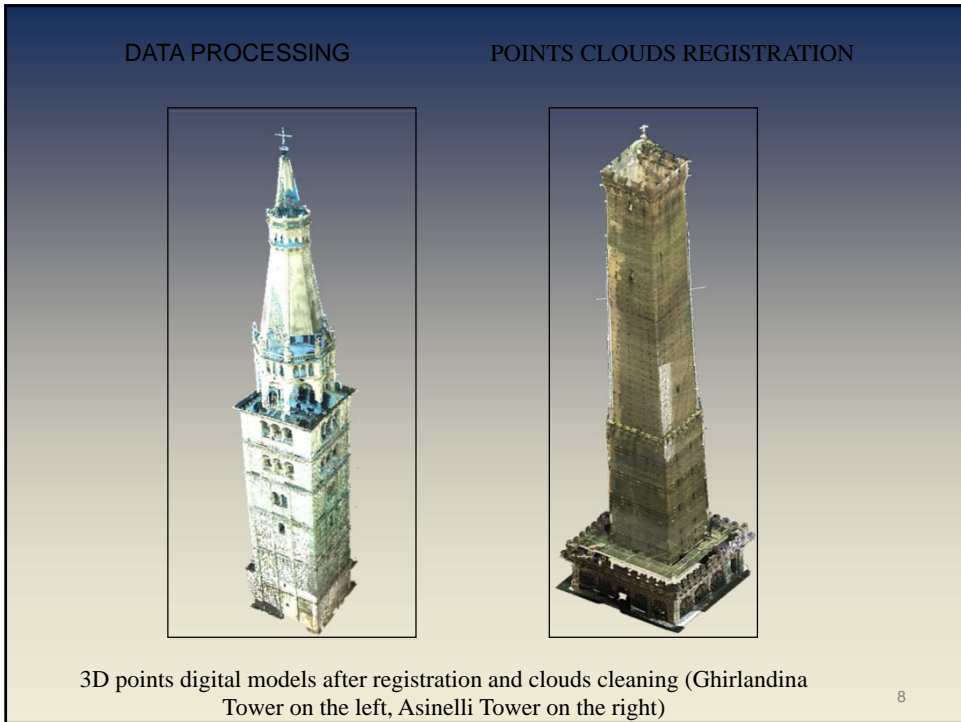
Reflective targets  
( 7,5 cm size)



Climber in action

## Targets position on Torre della Sagra



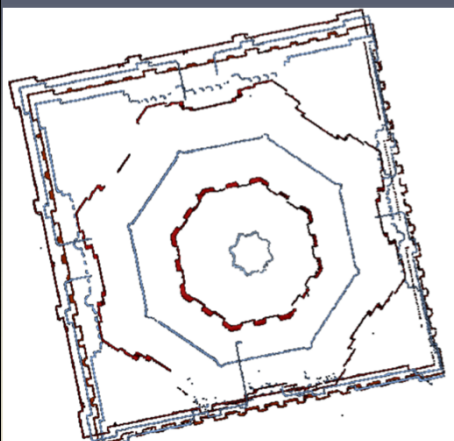


**Torre Ghirlandina and Duomo di Modena (Italy):**  
texturing of 3D model



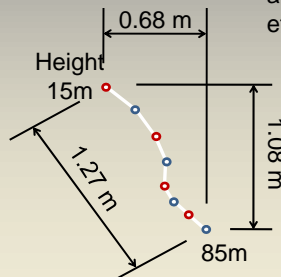
### Variations of axis inclination Torre Ghirlandina

#### Horizontal sections



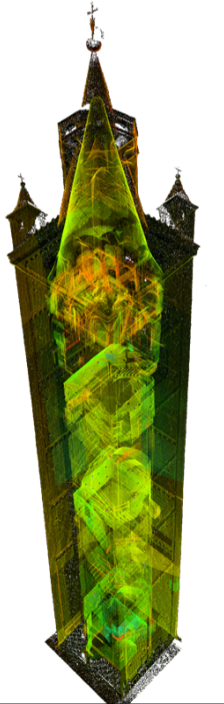
Horizontal projection of barycenters of section made every 10 m from 15 m height to the top

Axis inclination is due to intervention made during the construction (vertical correction) at about 40 m height and to subsidence effects.

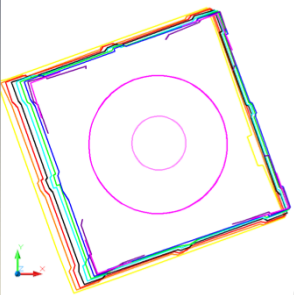


The reconstruction resolution of the barycentric axis could be increased through the definition of an increasing number of horizontal slices.

### Torre della Sagra – Carpi (MO) Italy

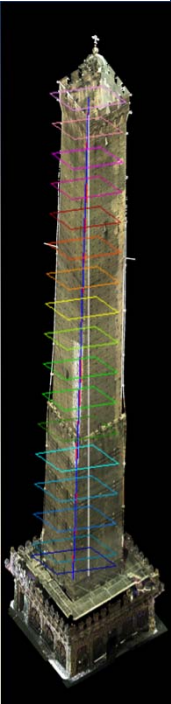


The structure is quiet compact , even if it is 50 m height: the tower showed a rotation as rigid body towards North-West with respect to the basis.



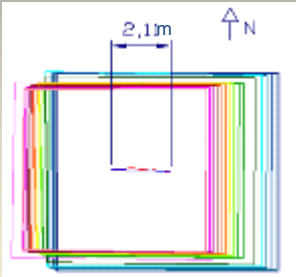
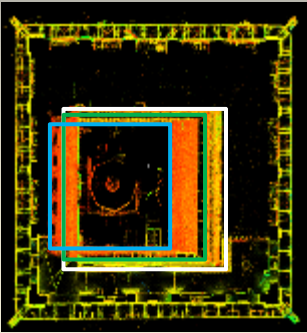
The horizontal sections ( made every 5 m) show the inclination towards north-west ( nord:X axis) and the section narrowing to the top.

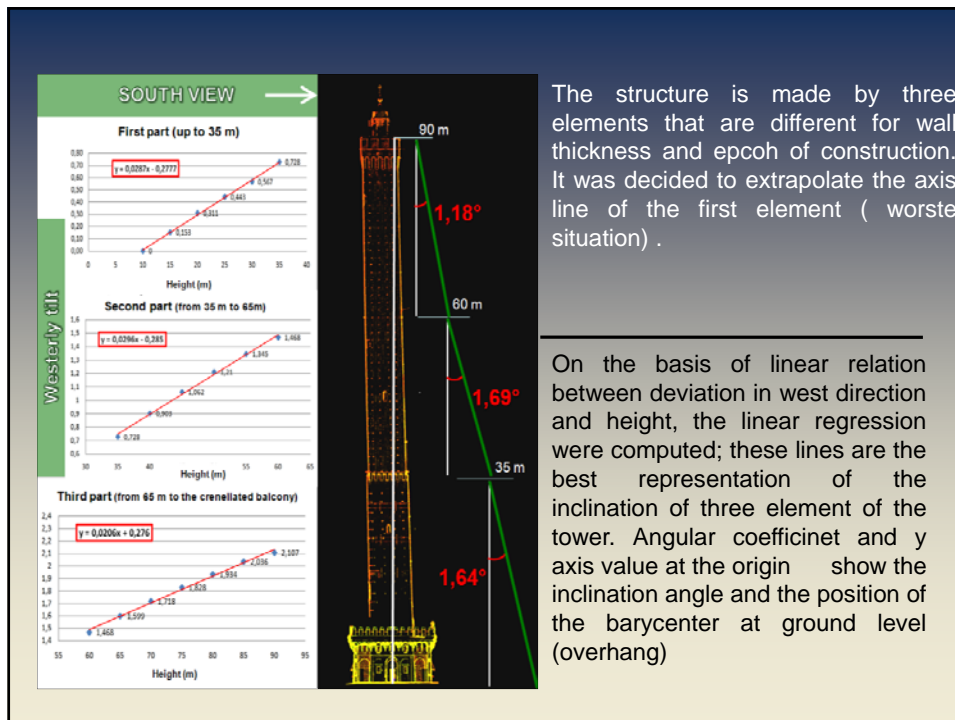
### Torre degli Asinelli – Bologna, Italy



Vertical axis analysis was made creating sections every 5 m. The axis trajectory shown a significant deviation of the structure: in west direction with an overhang of the top of 238 cm was measured while in north-south direction was of about 4 cm),

A measurement made in 1912 showed an overhang of 225 cm: it means that in one century an average variation in overhang of 1,3 mm per year has been observed.



### Summary of Geometrical characteristics

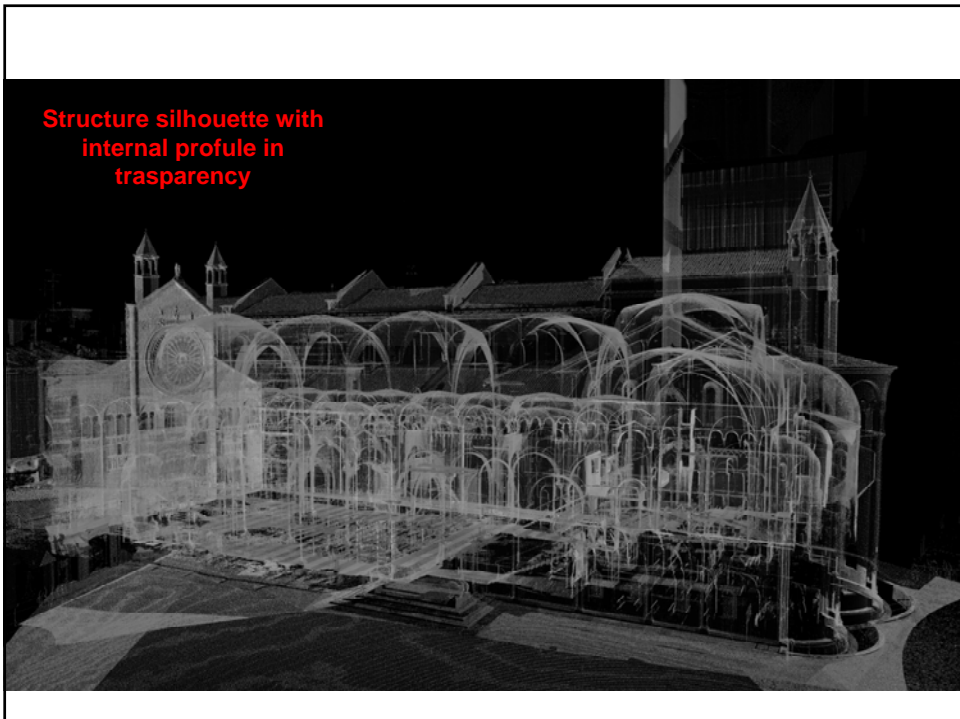
	Height	Overhang		Average inclination of barycentric axis
		maximum value	Direction	
TORRE DEGLI ASINELLI	97,38 m	2,38 m	West	1,51 °
TORRE GHIRLANDINA	88,82 m	1,54 m	South-West	1,04°
TORRE DELLA SAGRA	48,51 m	0,71 m	North	0,84°

## Diagnostics with TLS

### DUOMO DI MODENA (Italy)

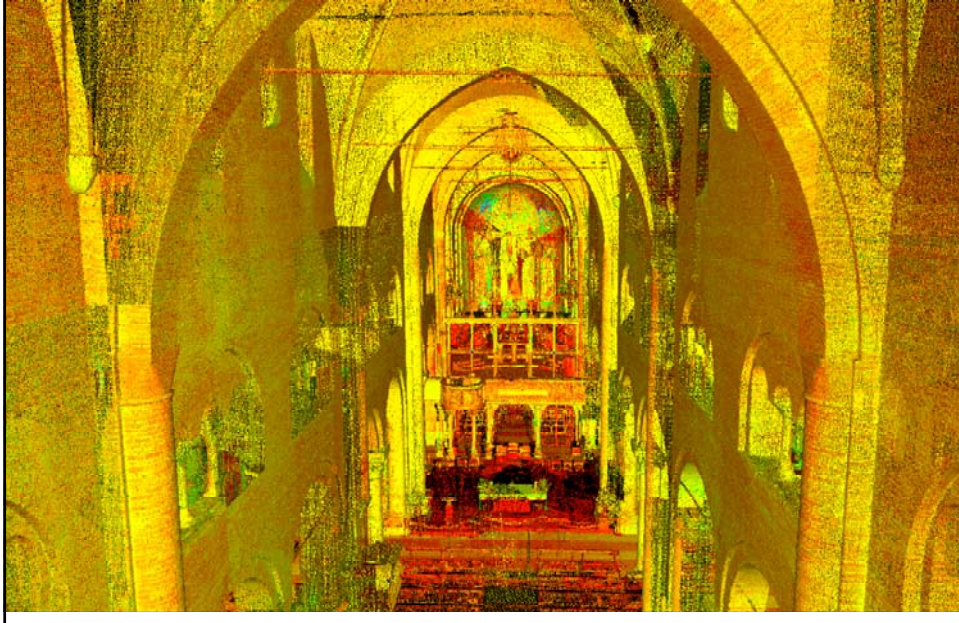


### Structure silhouette with internal profile in transparency



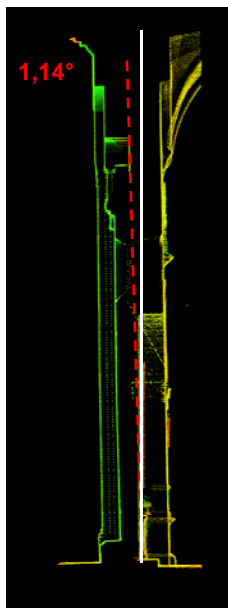


### Orthographic Internal view



### Example of vertical sections

#### ← North lateral facade

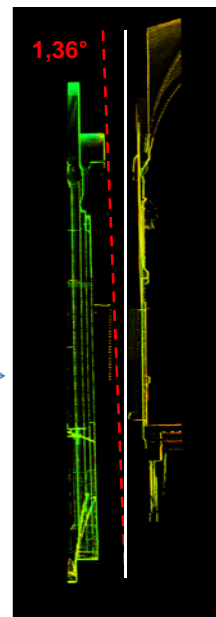


- Inclination of **1,14°** towards North Nord

- Wall thickness of **113 cm** at the middle section

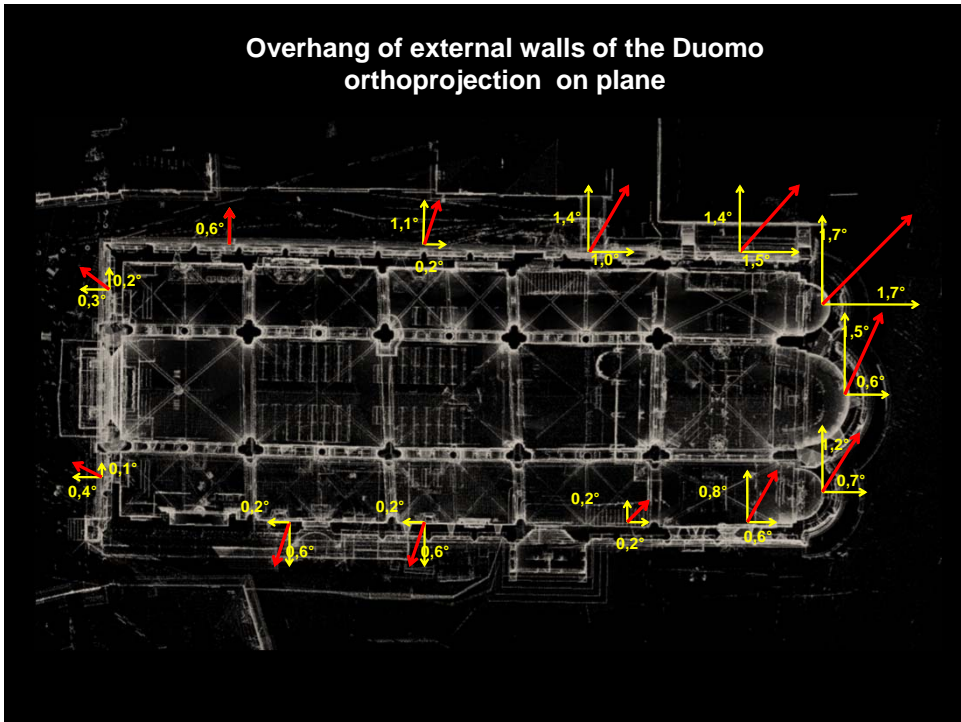
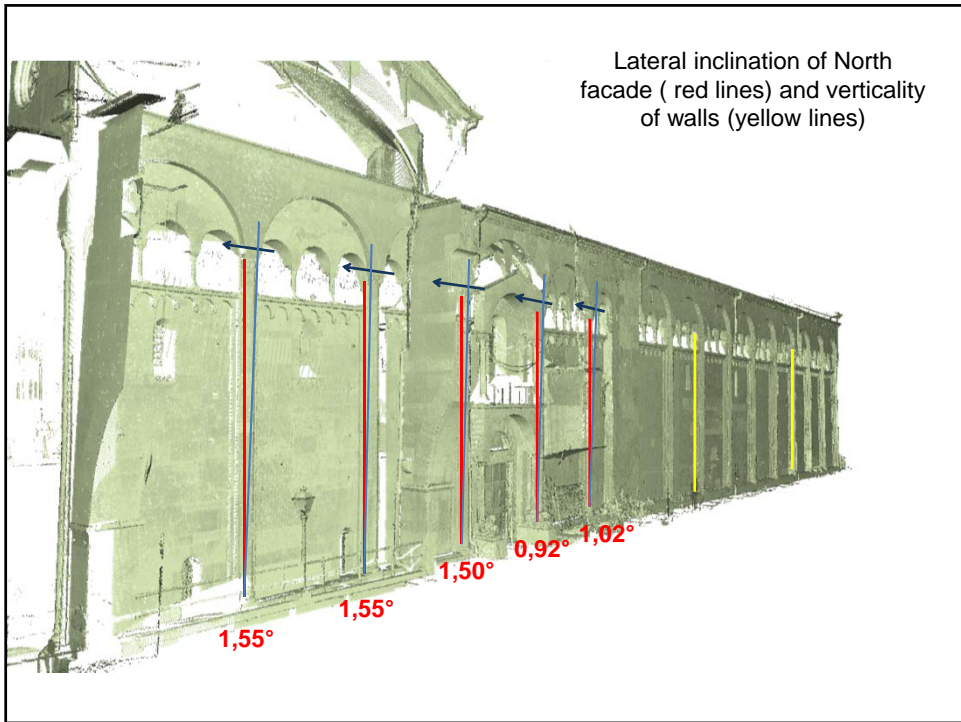
- Wall thickness of **54 cm** at the hole level

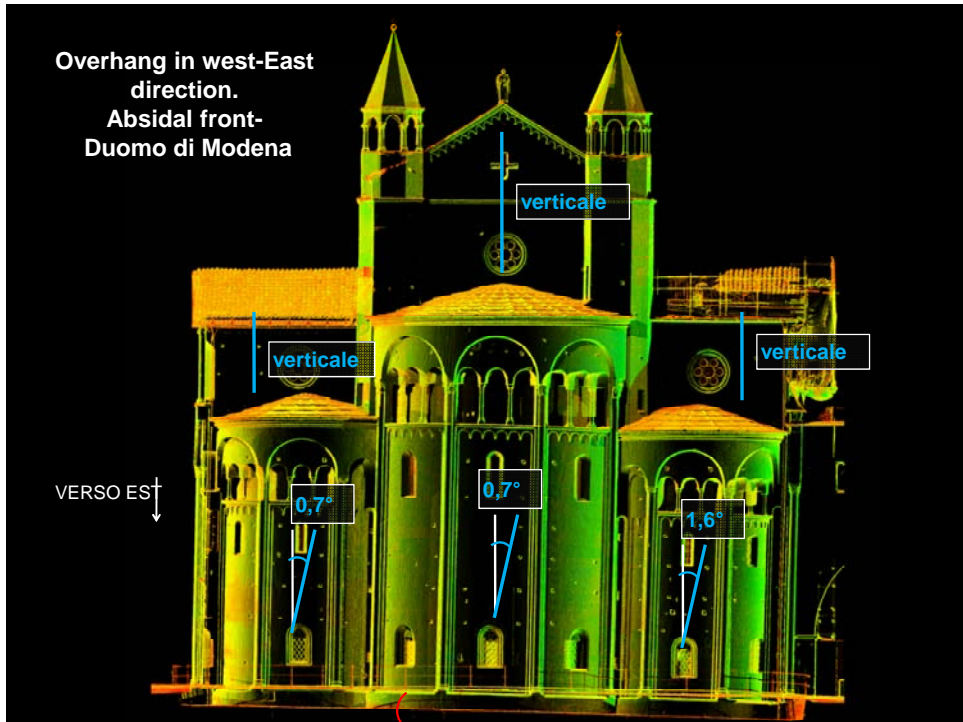
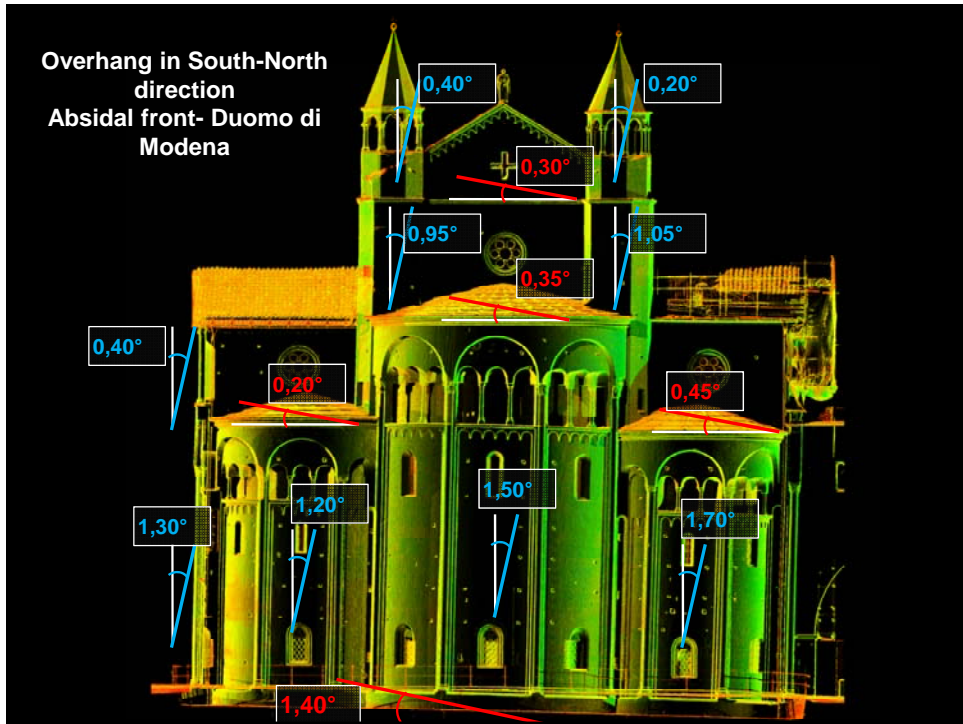
#### South lateral facade →



- Inclination of **1,36°** to the exterior l'esterno-North

- Wall thickness is **110 cm** above and behind the corroir





## Conclusion

TLS surveying for 3D restitution and geometrical determination of the structure with good accuracy at a centimeter level

The surveying procedure and processing methods allow an accurate determination of towers height and inclination. The achieved accuracy (centimetric-level precision) is a great result in relation to the short survey and processing time which was required.

The exact and clear location of the geometrical barycenter, related to the horizontal slice at the base of the towers, could be sometimes very difficult; the actual overhang can only be known by means of the barycentric axis extrapolation to the ground level.

The application shows the diagnostic use of TLS 3D surveying; very important tool for conservation and restauration intervention



Laboratory of Geomatics  
Dept. of Mechanical and Civil Engineering  
University of Modena and Reggio Emilia



XXIV FIG International Congress 2010 - 11-16 April, Sidney, Australia Session TS\_4D - TLS applications I - paper n.4445