

Laser scanning the Garisenda and Asinelli towers in Bologna (Italy): detailed deformation patterns of two ancient leaning buildings

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Abstract

The Asinelli and Garisenda towers are the main symbol of the city of Bologna (Italy). These leaning towers, whose heights are about 97 m and 48 m respectively, were built during the early 12th century and are two of the few surviving ones from about a hundred tall medieval buildings that once characterized the city. Therefore, they are part of the Italian cultural heritage and their safeguard is extremely important. In order to evaluate in detail the deformations of these towers, in particular the deviations from a regular inclination of their walls, the terrestrial laser scanning (TLS) has been used and an efficient direct analysis method has been developed. The towers have been scanned from 6 viewpoints, providing 19 point clouds with a complete coverage of the visible surfaces **with large overlap areas**. For each tower, after the registration of the partial point clouds into a common reference frame, an accurate morphological analysis of the acquired surfaces has been carried out. The results show several zones affected by significant deformations and inclination changes. In the case

1 of the Asinelli tower, for which a finite element model is available, the results have also been
2 interpreted on the basis of the static load and normal modes. The correspondence between the
3 measured deformation and the theoretically expected deformation, caused by a seismic
4 sequence, is clear. This fact suggests a high sensibility of the tower to dynamic loads.
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6 Although a direct evaluation of the risk cannot be carried out with the obtained results, they
7 lead to the general indication that the structural health of these buildings must be frequently
8 checked and that man-made loads (e.g. vibration due to vehicular traffic) should be avoided or
9 at least reduced.
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22 **Keywords:** Mason Building; Leaning Building; Middle Ages; Deformation; Terrestrial Laser
23 Scanner.
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29 **1. Research aims**

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31 Ancient buildings are an important component of the Italian cultural heritage and this is the
32 case of the Asinelli and Garisenda *leaning* towers in Bologna, often called the Two Towers,
33 whose heights are about 97 m and 48 m respectively. They are among the most important
34 symbols of the city, and their safeguard cannot be ignored.
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41 *Terrestrial laser scanning (TLS) technique acquires the geometry of an observed*
42 *surface with a high spatial sampling density. TLS is used in architectural building surveys to*
43 *reconstruct building shape.*
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48 In this paper a methodological approach to the TLS-based data processing is proposed
49 in order to recognize the deformation patterns of the Two Towers. In particular, for each
50 tower wall, the observed shape is compared with two reference planes (a vertical xz -plane
51 with x parallel to the corresponding basement side and a best fit plane) to provide the
52 deviations from a constant inclination. Therefore, this method allows a recognition of possible
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