

# A Greek goldmine

In March, six master students of Built Environment have studied the secrets of the renowned acoustics in ancient Greek amphitheaters. Prior to their project they managed to commercialize their plan and have sponsors fund part of their adventure. They were allowed to 'practice' in Dutch open-air theater De Kersouwe in Heeswijk-Dinther. Their thorough preparation helped the students collect a wealth of data in Greece in six days, which they brought home to the Laboratory for Acoustics.

Students of Built Environment don't go on measuring expeditions usually. In the words of lecturer Constant Hak, it's a dormant course within the Building Physics and Services master track that requires a great amount of dedication that isn't compensated with any credits. Acoustic measurements were done in Lapland ice hotel Jukkasjärvi in 2002. Two years after that, students studied Icelandic turf houses. The last measuring expedition traveled to an underground city in Cappadocia, Turkey in 2006. A few times the idea fizzled out after students realized how much effort they would have to put in.

This spring, master students Barel Nicolai, Adonia Diakoumis, Bas Peeters, Niels Hoekstra, Chris van Loenen, and Marco van der Wilt proved they had the passion and drive to go on a measuring expedition. On their own initiative, supervised by Constant Hak and Remy Wenmaekers, they traveled to Greece to research the secrets of the great acoustic qualities of Greek amphitheaters. They used an innovative wireless measuring technique to map the acoustic properties of three ancient-Greek theaters. Does a good view equal good sound?

## Four hours of sleep tops

The Odeon of Herodes Atticus was built around 150 A.D. The theater of Argos dates back to the third century B.C., the theater of Epidauros was built in the fourth century B.C. They are located relatively close to Athens. Herodes Atticus is the smallest, and the only one with a façade. Tourists are not allowed on stage or seats. The Eindhoven students are honored they are allowed in the

theater. Instead of the typical half-moon shape, Argos looks more like a wedge, and has been carved from a rock wall. It's in a very bad state of repair. Not all original 20,000 seats are available anymore, but audiences can still watch performances from the lower rows of seats. Epidauros is the most remote of the three theaters. It's located in a wooded area, so it was completely quiet at night. In fact, it was so quiet that the only sound the researchers heard was a stray dog howling in the distance.

The TU/e students reported at the theater gates before dawn, and the guards closed them after they had left again late at night. Days were long and the mandatory break - so tourists had Argos and Epidauros to themselves - wasn't relaxing exactly, as they had to guard their equipment, and evaluate and adjust their measuring tactics. On the other hand, they were able to observe the tour guides who all demonstrated a range of sound effects: clapping, dropping a coin, ripping up paper, and lighting a match et cetera. They had four hours of sleep a night at the most.

## All measurements were done during the day and at night

All sounds, including that of dogs, crickets, tourists, traffic, someone spraining their ankle and 'the worst street performer ever' were recorded by the twenty microphones the students had at their disposal. They measured at two hundred positions at each theater, distributed over ten measure lines. For every position they used two sound sources, and by rotating these in five steps, the gathered at least 2,000 source-receiver combinations.

Fewer combinations were unacceptable, as the acoustic field in theaters can differ from seat to seat. And since acoustics are different after a cool night than after a hot day, all measurements were conducted mornings and nights. And now they're sitting on a gold mine. That is, when all sound recordings have been listened to and the 40-second transmissions have been found, filtered out, downloaded to special software, and converted into impulse responses. The latter are signals shown in a graph that show the response to a transmitted 'blow'. Processing the data will take up another few weeks of full-time work for two to three students. The team wants to filter six thousand impulse responses from their recordings. That number represents a large amount of data, and it's complete, too: the students have taken into account temperatures, humidity, and wind. Their invaluable results can validate acoustic calculations used for the design of inside and outside spaces. This outcome - a unique set of useful data - is the reward that kept the students going. As far as research goes, they are not done yet. Apart from the meticulous mapping of the acoustics of an amphitheater, the results will also be used for ongoing research at Building Acoustics on sound propagation in the built environment, and room and stage acoustics. The measuring results will be stored carefully, so future studies can benefit from them as well.

For more photos and information, go to [www.ancient-acoustics.nl](http://www.ancient-acoustics.nl).

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The Argos theater.



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