2nd International Conference on Bio-based Building Materials &
1st Conference on ECOlogical valorisation of GRAnular and FIbrous materials

June 21th - 23th 2017
Clermont-Ferrand, France

THE COMPRESSIVE STRENGTH OF MYCELIUM DERIVED FROM A MUSHROOM PRODUCTION PROCESS

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Abstract
This paper presents the context of the research and a literature review into the state of the art of creating mycelium products. A theoretical framework is described, the production process of mushroom farmers is researched and used to create mycelium composite with good mechanical properties, with a focus on compressive strength. The main goal of the research is to create blocks of mycelium composite that can be used in the building industry and can be tested on compressive strength in a wall configuration. Collaborating with local mushroom farmers and bio polymer specialists the influences of the type of mycelium, the growth (circumstances), the (type of) substrate, and the processing on the mechanical properties of the mycelium blocks are researched. Series of specimen and blocks with different properties and growing conditions are produced together with the mushroom farmer and tested. A rudimentary exploration of joining techniques and possible shapes of the blocks supports the design and construction of three small wall specimen with mycelium composite blocks. These proofs of concept are tested on compressive strength. The results are presented in this paper.

Keywords:
Mycelium; composite; mechanical properties; compression load; product design

1 INTRODUCTION

1.1 Context

The current building industry in the Netherlands is not using a lot of locally (re)growable bio based materials or (waste) flows from the agricultural industry. That however could be a major step towards a more sustainable building industry and build environment, where buildings become bio based material storages during their life time, after which the materials can be re-used.

The ‘blocks’ used by mushroom farmers to grow mushrooms (Figure 1.) are an example of (re)growable bio based materials possibly suitable for use in the building industry. In these ‘blocks’ a network of hyphae binds the substrate together, a composite material emerges. To grow mycelium composites different fungi from the basidiomycota can be used. Two species from this group of fungi, the Trametes versicolor (White rot fungi) and the Pleurotus ostreatus (Oyster mushroom) produce a high density of mycelium and grow relatively easy and fast [Blauwhoff D.R.L.M, 2016] [Montalti M., 2017].

It is important the mycelium composite can be derived from the agricultural process with as little as possible extra costs or disruption of the current process of growing mushrooms. Second, as less processing as possible should take place in order not increase the footprint of the product envisioned or use more energy / resources.

Fig.1. Production of mushrooms with ‘blocks’.

As mycelium composite now is mostly created in industrial environments by a few companies, this ‘agricultural approach’ broadens the possibilities of the production of a light weight biodegradable building material that can be (re)grown.

1.2 Problem definition

In this research the product development of a non project based product and its properties are the focus as this is more favourable than project based innovations [Lichtenberg J.J.N., 2002].

The research process is organized in iterative circles as this connects well to the already iterative production processes of the mushroom farmer and deals with the complexity of product development for the building industry [Smit M., 2008], searching for integrated solutions.

To determine if mycelium composites could be used in the building industry research into three basic properties, its structural behaviour, its thermic and acoustic behaviour and its behaviour towards water and moisture are necessary. Within these properties, iterative circles are executed according to Figure 2.

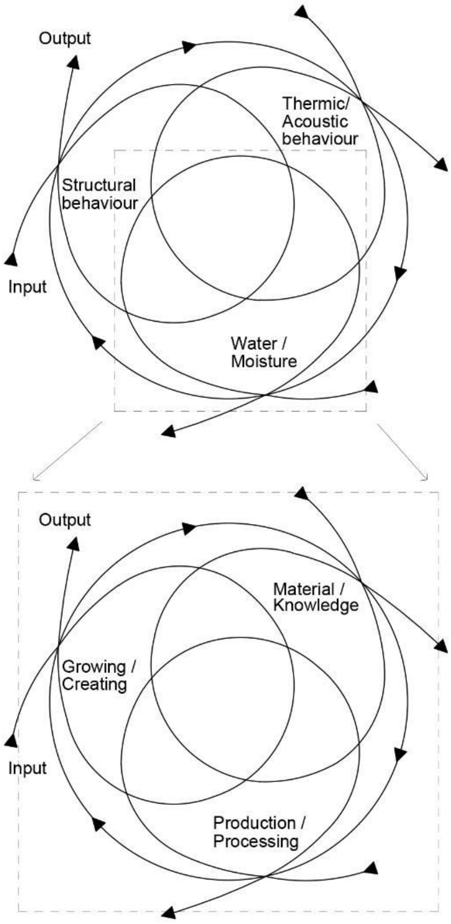

Fig.2. Diagram research process

The research is set up and lead by Jeroen da Conceição van Nieuwenhuizen. The first part of the research, described in this paper, focusses on the compressive strength of mycelium as part of the determination of its structural behaviour. It is executed together with two researchers, Davine Blauwhoff and Marloes de Werdt, and two graduation students building engineering, Willem van der Zanden and Dennis van Rhee.

The main goal of the research is to create blocks of mycelium composite and test them on compressive strength. Simultaneously gaining better insight in the growing conditions, the processing and other parameters that influence the (compressive) strength and related product properties.

How can mycelium from mushroom farmers be processed into usable blocks for the building industry? What influences the compressive strength and how can we improve that in the future?

1.3 State of the art, a comprehensive review

Research into mycelium already resulted in many small build projects such as the Hi-Fi project [Rajopal, 2014] [Nagy, D.; Locke, J.; Benjamin, D., 2015], a Tiny House [Ecovative, 2013] and various conceptual designs. Other examples are MycoFoam packaging material [Zeller, P.; Zocher, D., 2012] [Ecovative. 2015] and Myco Board, a mycelium based plate material that can be used as a completely natural alternative for chipboard and MDF that uses formaldehyde to glue the wood particles together [Tudryn G.J., 2014] [Bayer E. en McIntyre G., 2011], Sandwich panels [Jiang et all., 2016], art [MycoWorks. 2016] [Ross P., 2014] and the research of Officina Corpuscoli [Montalti M., 2017]. Often the presented proofs of concept / results are project based and lack research into the properties of the type of mycelium composite used. In addition to that, limited literature is available that describes how to develop better properties of mycelium composite based building materials, especially mycelium directly derived from the mushroom production process. Two recent graduation reports from Lelivelt (Eindhoven University of Technology) and Blauwhoff (Delft University of Technology) provide initial insights however [Lelivelt R., 2015] [Blauwhoff D.R.L.M., 2016]. From the much broader review than mentioned here the insights and data where used throughout the research, as for instance described in chapters 4.2, 4.3 and 4.4.

2 THEORETICAL FRAMEWORK

The research process was done in iterative loops including a hands on learning from failure component. Parallel to the literature review a research into the production process at Verbruggen paddenstoelen b.v. and into properties of the mycelium was done in the first phase of the research. For the first experiments mycelium blocks directly from the production process where used. In the second phase (the second loop), new specimen where (re)grown in cylinder moulds (not bio based) to create an accurate standard and outcome of the compression load tests. To create insight into at what moment in the agricultural production process the strongest material could be ‘harvested’ four variations of specimen were created.

In the same phase a rudimentary product development exploration led to the choice for a certain type of mycelium ‘bricks’ to be used for the wall configuration. In the third phase the mycelium that performed best during the prior executed tests was put into moulds to grow. After that the ‘bricks‘ where dried and tested as a wall configuration under compression load. The interpretation of the results led to conclusions and recommendations for future research and for Verbruggen paddenstoelen b.v.

3 THE FIRST ITERATIVE LOOP

In this phase the process at Verbruggen was analysed. Verbruggen sells 3 types of Oyster mushrooms: Pleurotus Ostreatus var. Spoppo, Pleurotus citrinopileatus and Pleurotus Salmoneostramineus. The grey, yellow, pink and type. The mushrooms are grown on blocks created from bio and non bio substrate made with straw and grass seed hulling. After harvesting two or three 'crops' the blocks are mixed in the new substrate. But they can also be used as soil improvement. In both situations this is more than a circular use of bio based resources when there are no pesticides in the straw. The production process of mushroom consists out of different phases as drawn below (Figure 3.), and is constantly improved by data coming out of the process (iteration) by Verbruggen.

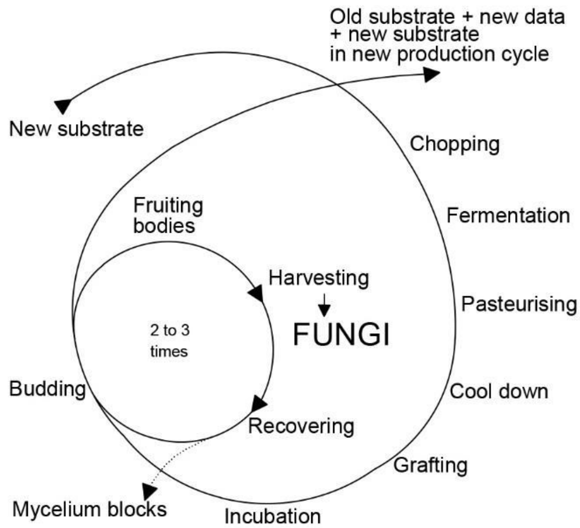

Fig.3. Diagram of the iterative production process at Verbruggen paddenstoelen b.v.

The second part of the research focussed on obtaining more information about the material of Verbruggen. A small fire test, floating test and measurement into moisture content of the blocks were done. Then first tests to compress the mycelium, create a process how to dry the blocks and how it could be coated where executed to create more insight in the material.

In the first tests to pressure the mycelium from Verbruggen series of different variants of mycelium (of oyster mushrooms) where put in a compression test on a non calibrated machine with an adjusted pressure head (Figure 4.). The coated variant came out the best, however it is assumed the 98 percent bio coating fills the air gaps and contributes to the strength.

The results of this phase showed that: (1) The blocks are reasonably fire resistant, (2) they are light weight and float for a long time, (3) sawing the blocks is not a good treatment as it breaks the outer 'blanket' of mycelium which is responsible for a large part of the materials strength, (4) coating can influence the test results and should be deleted from the process for now, (5) the material in this series has a low compressive strength. Most results comply with data from the literature review, although the mycelium described in literature is mostly not directly taken from an agricultural mushroom production process. Further research in a second loop into the material properties and production of specimen for testing is sought for to create a stronger mycelium composite.

Fig.4. First compression tests with three types of mycelium specimen in the first loop

4 THE SECOND ITERATIVE LOOP

4.1 Variants in growth

In the second phase of the research mycelium is put into moulds to (re)grow. Several variants were created by taking mycelium from the Pleurotus Ostreatus var. Spoppo (Grey Oyster mushroom) at different stages of growth: 7 days old and no fruiting bodies; 14 days old and no fruiting bodies; 28 days and one harvest of fruiting bodies; 44 days and one harvest of fruiting bodies and one recuperation period. Respectively the variants 1, 2, 3, and 4 in Figure 7. For variant 2, 3, 4, 10 specimen where tested, for variant 1 only 5 as the others where infected.

In this way it is possible to find out if the growth of the mycelium has an effect on the strength of the composite. Variant 4, gives the best results. This is mentioned by Ross also, recuperation enhances the compressive strength, next to heating mycelium specimen under pressure [Ross P., 2011]. The Pleurotus Ostreatus var. Spoppo was chosen in a visual test because of the good colonisation and coherence of the grown test blocks.

Fig.5. Drying the test samples, different labelled categories present the different variants

4.2 Norms for testing

There are no current norms for testing mycelium materials in the Netherlands. Norms such as NEN-EN 1052-1 (ni) Methods of test for masonry - Part 1 and NEN-EN-ISO-844 where used to determine the amount of specimens, size of specimen and the demands on the setup and execution of the tests.

The literature review shows tests by Ecovative are done according to ASTM D3574-11. This norm however is not applicable in The Netherlands. In the research of Lelivelt, Blauwhoff and Ecovative it is described that mycelium could be a substitute for EPS, therefore the NEN-EN-ISO-844 Rigid cellular plastics – Determination of compression properties [CEN-CENELEC, 2014] was used to setup and execute the compression tests. Norms to test bricks and materials alike are less usable as the specimen or wall configurations tested show brittle failure behaviour while mycelium shows ductile behaviour.

4.3 Values from the literature

The literature review shows that other mycelium materials, such as the Ecovative grow it yourself kit with an unknown fungus and substrate reaches values of 0,055 – 0,1 MPa under compression load [Ecovative. 2016]. The research of Lelivelt shows samples of mycelium with hemp that reach values of 0,024 – 0,093 MPa. Lelivelt during the testing first compressed the blocks with 100 Newton as a “pre load” to get out all enclosed air, and then re-loaded the samples with 200 Newton compression load to achieve these results.

4.4 The tests and results

The test samples where grown in cylindrical moulds. A Marius Utrecht oven type 68B was used to heat and dry the specimen to 80 degrees Celsius.(Figure 5.). Testing the cylindrical blocks was done with a calibrated Shimadzu type AGS-X.

From the overall test results per sample for every variant of grey oyster mushroom a graph was made. The test shows that after the compressive load was released a part of the deformation was elastic and a part was plastic deformation. This is also visible in the photographs of the test (Figure 6.).

Fig.6. Photos showing the start of loading, the maximum load, and the same specimen after elastic behaviour

The large plastic deformation area can be explained by the composition of the material. The plastic and elastic deformation occur partly at the same time. Because of the weakness of the material, no explicit buckling moment to which the research of Lelivelt refers to is seen in the graphics.

During the growing process of the mycelium composite the material contains a high percentage of water (average around 65%) which needs to evaporate to create a rigid composite. When all the moisture is gone, this leaves room for air, which is then enclosed in the material. Applying a compressive load on the composite causes the air to escape and forces the substrate to become more compact /dense.

The compressive strength at 10 percent deformation of variant 4 was 0,1 MPa (Figure 7.).

This 10 percent is done according tot the norm used. To compare, the compressive strength with other materials used for load bearing walls such as compressed earth blocks is 2 to 3,5 MPa [Sturm T., Ramos L.F., Lourenço P.B., 2014]. Research in hempcrete and woodcrete, bio based competition for mycelium composite blocks, show results of 0,8 MPa [Aigbomian E.P., Fan M., 2013] [Elfordy S. et al., 2008].

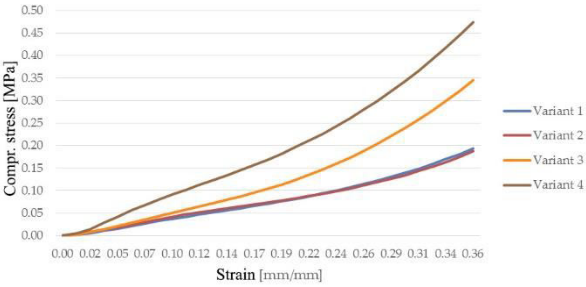

Fig.7. The test results of the second phase, stress-strain curve

5 DESIGNING THE ‘FUNGI BLOCKS’

For the design of the blocks an action research by design session was organized resulting in a categorisation of possible types of blocks. Different possibilities to connect them were part of this approach, such as (and not limited to) glueing, dry stapling, growing blocks together, piercing them with (bamboo) sticks, and finally using bio mortar. The categories where put into a multi criteria table with 5 main categories (structural form, building process, production process at farmer, production process block and innovativeness) For the different criteria in these categories weight factors where determined and a limited amount of multi criteria tables where filled in by different people. Here the remark must be made that this part of the research process should be classified as more practical, the multi criteria table served as a set of substantiating choices leading to a type of block.

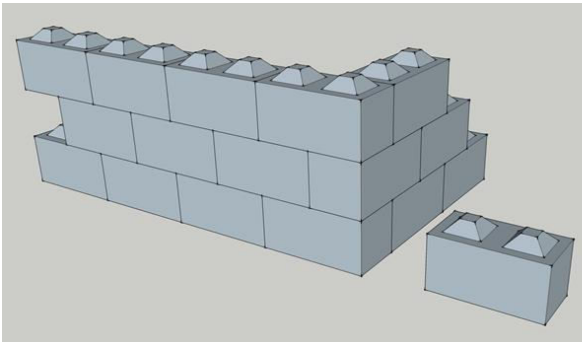

Fig.8. The chosen (Lego type of) block

Chosen was a Lego type of block (Figure 8.). The expected resistance against shear forces was an important issue (shape of the surface and size of surface against shear), as well as if it was possible to vacuum form the mould to grow the mycelium in. Other important criteria were if it would be possible for the farmer to produce these blocks in series with a press, and if they can be easily used by builders in a dry stapling method. The mycelium composite ‘ bricks’ could be an alternative to in the market concepts such as the Click Brick and the concrete Legio blocks [Daas, 2016] [Jansen A., 2013] taking into account the scale. It can also be an alternative for hempcrete blocks and compressed earth blocks.

6 TESTING THE WALL, THE THIRD LOOP

From the test with the cylindrical specimen the result of variant 4 was the best, therefore mycelium of 43 days (instead of 44) of the Grey Oyster mushroom was used for the third loop of the research.

The mycelium was taken by hand out of the production blocks and pressed into the moulds until 800 to 900 grams of material where in the mould (Figure 9.). The moulds, a total of 65, made out of PET-G, Polyethylene terephthalate, where disinfected with 70% bio ethanol. They where placed in a cell to grow for 18 days and dried afterwords in an oven at 80 degrees Celsius.

Fig.9. Production of the blocks, pictures above, growth at 7th day (third picture, below left), growth at 14th day (fourth picture, below right side)

For the method and criteria for testing a wall under compression load the norms as described in chapter 4.2 where used. Leading was the NEN-EN-ISO-844 Rigid cellular plastics – Determination of compression properties [CEN-CENELEC, 2014], although this norm can only be used to a certain extend.

Fig.10. Testing three wall specimen. Intron type 5985

A total of three walls made out of 'mycelium bricks' where tested under compression load (Figure 10. and Figure 11.). The outcome where three almost identical stress strain curves (Figure 12.). From these results can be concluded that the average strength of the tested walls is 0,03 MPa. This complies with the statement in Sturm et al. that the compressive strength of a wall configuration is about 0,3 to 0,4 that of the tested singe specimen [Sturm T., Ramos L.F., Lourenço P.B., 2014].

Some remarks have to be made. The walls did not collapse, but showed significant elastic and plastic behaviour. As the horizontal displacement was measured it shows for the limited hight of the sample no buckling behaviour. But some local destruction because of imperfections of the 'bricks' was clearly seen.

Fig.11. Photos of the test showing the start of loading, at maximum load, and after elastic behaviour

Some other remarks can be made: As there is no suitable standardization is is not clear weather the tests where conducted completely suitable for the material. The imperfections of the blocks due to shrinkage and the material being anisotropic together with the air inside (because the moisture was taken out) has significant influence on the behaviour of the tested walls. The results from these tests where not done with extra fibres in the substrate such as hemp and not pre pressured, as in the case of the research of Lelivelt. The choice of drying the blocks after 18 days as the should be fully grown is purely done by visual inspection, no extra research to check that was done.

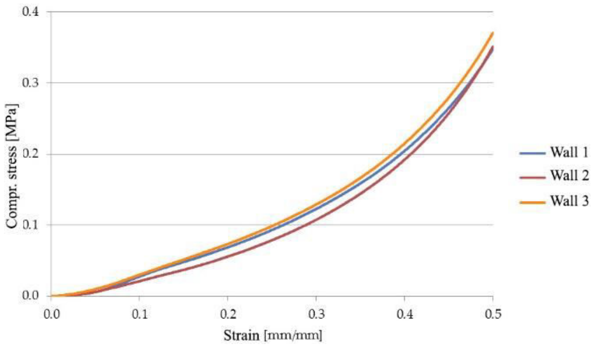

Fig.12. Diagram of the results of the third phase, stress-strain curve

7 CONCLUSIONS AND DISCUSSION

1. Conclusion of this research is that from the perspective of compressive strength the material as tested is not useable in structural walls for buildings, but can be used as non load bearing (insulation) material for walls.

   The best results for the cylindrical specimen show an average compression load of 0,1 MPa, much lower than currently used materials for these types of walls. The outcome of the tests are in the same range as the tests by Lelivelt [Lelivelt R., 2015], but with some significant differences. First of all the tests where performed with mycelium which came directly from the agricultural process. Secondly, the samples where not 'pre-pressured' nor was any fibre, such as hemp fibre, added as Lelivelt did [Lelivelt R., 2015].

2. From the research of Davine Blauwhoff one can conclude that a possible production method for stronger blocks can be a heat pressure method [Blauwhoff D.R.L.M., 2016]. Heat pressed samples show a much higher strength under tension than the samples that are not heat pressed. An underlying reason for this is that the enclosed air in the material is released while drying. It creates a more dense composite. In addition to this, the assumption is that the biological structure of the mycelium

reacts to the heat and changes (partly) from cellulose to lignin, behaving like a glue. More research is necessary however to see if these assumptions are correct, to what extend they can contribute to the strength under compression load and if this can be connected to the agricultural process without disruption and without extensive costs.

3. Literature states that mycelium composites should be grown without the production of fruiting bodies. This research shows however that the mycelium for the composite blocks can be taken out of the agricultural process after mushrooms where harvested. This means the agricultural process can continue.
4. The behaviour of the blocks in the wall configuration and the cylinders shows plastic and elastic behaviour. Apart from the strength of the material, the deformation would initially cause problems for a structural application. However if the materials elastic and plastic behaviour can be controlled or designed it could be well suited for earthquake areas. This because it will not break brittle and become unstable as for instance stone walls do. Lelivelt also refers to that as the material having a good shock absorption.
5. Even though the mycelium composite is not strong enough for structural elements, its light weight and the enclosure of air suggests that it could be used as insulation or as filling in walls that are not load bearing. Further research into thermal and acoustic behaviour and response to water and moisture is therefore required.

8 FUTURE OUTLOOK

1. It can be interesting to change the type of mushroom from Oyster mushroom to White rot fungi. However Verbuggen needs to grow mushrooms that can be harvested to serve as food, and that is not the case with the White rot fungi. Also it is very likely the production process needs to be changed as the growth of the White rot fungi is (partly) different form the Oyster mushrooms. However a recommendation for future research can be, as there is still an enormous variation possible with the substrate and fungi, more research is necessary to see if other mushrooms deliver better results.
2. The fibres in the substrate can be changed, or fibres can be added. Long fibres instead of shorter ones. This can positively influence the plastic and elastic behaviour. It is already mentioned by different other authors that hemp fibres, kenaf or maybe even bamboo can be used [Blauwhoff D.R.L.M., 2016] [Akil. H et al, 2011]. However this means it needs to fit in the agricultural production process. Research needs to be done what are the implications for the growth of the mushrooms and the rest of the agricultural process.
3. It is to be expected that the process of drying the blocks, as done in this research, becomes expensive for the farmer if real production would occur. At the same time the current process creates blocks with deviations in shape and size, caused by the drying process and the (not stiff enough) moulds. The plastic deformation also needs to be smaller if structural applications such as load bearing walls would be the focus for the possible product. Therefore doing tests where the mycelium is pressured under a certain heat (in a mould) could be interesting. Especially if this could be done in series and could make the drying process obsolete and the amount or size of the deviations of the product smaller.
4. The materials used to grow the mycelium and make moulds as well as de drying process are not bio based, there should be research done into how the process of creating mycelium blocks could also become more bio based, using less energy and if possible less materials.
5. Research can be done to what extent the shape of the blocks or bricks can positively influence the strength of a wall under compression load. The overall behaviour of the wall specimen is different from the cylindrical specimens. In the wall configuration failure can be the result of a combination of different forces such as compression, shear and flexural forces. Also the height and length of a wall in reality will influence the strength and its behaviour. This should be researched.
6. Theoretically this material seems to have three phases. First the air and soft material parts are pressured out and soft parts are densified, Then the material deforms elastic until a 'sort of buckling point'. And then the material deforms plastic, but does not collapse. After taking the load of the material it deforms back partly elastically. More research into this is necessary as this theory is not observed completely in the tests performed.

9 ACKNOWLEDGEMENTS

We thank John Verbruggen for his help throughout the whole process. Tom Kretschmann for his comments as second independent mentor of the students. And last but not least to the people in the workshops that helped with the tests, Marco van Ras, Hans de Wit, Matti Kop, Hans Lamers and Theo van de Loo.

10 REFERENCES

[Aigbomian E.P., Fan M., 2013] Aigbomian, E. P., Fan, M. Development of Wood-Crete building materials from sawdust and waste paper. Construction and Building materials, 40, 361-366. 2013.

[Jansen A., 2013] A. Jansen B.V. Legioblock stapelbare betonblokken. van https://www.youtube.com/watch?v=CeUKtj-_p0Y . Accessed: 13 October 2016.

[Akil. H et. al., 2011] Akil, H., Omar, M., Mazuki, A., Safiee, S., Ishak, Z., Abu Bakar, A. Kenaf fiber reinforced composites: A review. Materials and Design. 4107-4121. 2011.

[Blauwhoff D.R.L.M., 2016] Blauwhoff, D.R.L.M., Mycelium Based materials: A case on Material Driven Design and forecasting acceptance. Delft University of Technology. 23 May 2016.

[CEN-CENELEC, 2014] International Standard. NEN-EN-ISO 844, Rigid cellular plastics – Determination of compression properties. CEN-CENELEC Management Centre. 2014.

[Daas, 2016] Daas Baksteen Zeddam B.V. 2016. ClickBrick. Available: http://www.daasbaksteen.nl/nl/

Gevelsystemen/ClickBrick/page.aspx/49. Accessed: 13 October 2016.

[Ecovative, 2013] Ecovative. 2 july 2013. Ecovative's Mushroom Tiny House. Ecovative. Available: https://www.youtube.com/watch?v=BUxael8qV78

Accessed 14 February 2017.

[Ecovative. 2015] Ecovative. We grow materials. Available: http://www.ecovativedesign.com/. Accessed: 14 February 2017.

[Ecovative. 2016] Ecovative. 2016. Material Specifications. Available: http://giy.ecovativedesign.com/ material-specifications/. Accessed: 01 September 2016.

[Elfordy S. et. al., 2008] Elfordy S., Lucas, F., Tancret T., Scudeller, Y., Goudet, L. Mechanical and thermal properties of lime and hemp concrete ("hempcrete") manufactured by a projection process. Construction and Building Materials. 22, 2116-2123. 2008.

[Jiang et all., 2016] Jiang L.,Walczyk D., McIntyre G.,Bucinell, R. A new approach to manufacturing biocomposite sandwich structures: mycelium-based cores. InProc. ASME 2016 International Manufacturing Sci. Eng. Conf. 2016.

[Lelivelt R., 2015] Lelivelt R., Lindner G., Teuffel P., Lamers H. The production process and compressive strength of mycelium based materials. First International Conference on Bio-based Building Materials; Clermont-Ferrand, France. 22-24 June 2015.

[Lichtenberg J.J.N., 2002] Lichtenberg, J.J.N. Ontwikkelen van Projectongebonden Bouwproducten. Phd Thesis. Eindhoven University of Technology. 2002.

[Montalti M., 2017] Montalti M. Officina Corpuscoli. The Future of Plastic. Available: http://www.corpuscoli.com/ projects/the-future-of-plastic/ . Accessed: 14 February 2017

[MycoWorks. 2016] MycoWorks. Redefining leather with mycelium: Creating materials with the power of organic technology. Available: http://www.mycoworks.com/. Accessed 30 August 2016.

[Nagy, D., Locke, J., Benjamin, D., 2015] Nagy, D.; Locke, J.; Benjamin, D.; Computational Brick Stacking for Constructing Free-Form Structures. Modelling Behaviour. Springer International Publishing. Pp 203-212. November 2015.

[Rajopal, 2014] Avinash Rajagopal. Behind "Hy-Fi": The Organic, Compostable Tower That Won MoMA PS1's Young Architects Program 2014. Available: http://www.archdaily.com/477912/behind-hy-fi-the-entirely-organic-compostable-tower-that-won-moma-ps1-young-architect-s-program-2014 . Accessed 14 February 2017.

[Ross P., 2011] Ross P. Method for producing fungus structures. US Patent Pub. No.: US 2012/0135504 A. Pub. Date: May 31, 2012. Filed 28 November 2011.

[Ross P., 2014] Ross P. Superflux. Mycotecture (Phil Ross). 2014. Available: http://designandviolence.moma.org/mycotecture-phil-ross/. Accessed 14 February 2017.

[Smit M., 2008] Smit M. Naar een Cyclisch Iteratief Ontwerpproces en Ontwerpomgeving, leren van ervaringen. PhD Thesis. Delft University of Tehnology. 2008

[Sturm T., Ramos L.F., Lourenço P.B., 2014] Sturm T., Ramos L.F., Lourenço P.B., 2014. Characterization of dry-stack interlocking compressed earth blocks. Materials and Structures (2015) 48:3059–3074. Received: 23 January 2014 / Accepted: 8 July 2014 / Published online: 18 July 2014

[Travaglini, S., Noble, J., Ross, P. G., Dharan, C. K. H.] Travaglini, S., Noble, J., Ross, P. G., Dharan, C. K. H. Mycology Matrix Composites. Proceedings of the American Society for Composites, Twenty-Eighth Technical Conference. Pennsylvania, USA. 9-11 September 2013.

[Tudrin G.J., 2014] Tudryn, G.J. A Formaldehyde-Free, Sustainable Alternative for the Engineered Wood Industry. Radtech Report, Issue 2. pp 40-45. 2014.

[Bayer E., McIntyre G., 2011] Bayer E. en McIntyre. G. „Method for producing rapidly renewable chitinous material using fungal fruiting bodies and product made thereby". USA Patent US 8,001,719 B2, 23 August 2011.

[Zeller, P., Zocher, D., 2012] Zeller, P.; Zocher, D.; Ecovative's Breakthrough Biomaterials. FUNGI, volume 5(1), pp 51-56. 2012.