Acoustics for amplified music and a new, variable acoustics technology that includes low frequencies

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ABSTRACT

Surveys among professional musicians and sound engineers reveal that a long reverberation time at low frequencies in halls during concerts of reinforced music such as pop and rock, is a common cause for an unacceptable sounding event. Mid- and high-frequency sound is seldom a reason for lack of clarity and definition due to a 6 times higher absorption by audience compared to low frequencies, and a higher directivity of speakers at these frequencies. A new technology of inflatable, thin plastic membranes presents a solution to this challenge of needed low-frequency control. It is equally suitable for multipurpose concert halls that need to adjust their acoustics by the push of a button and for halls and arenas that only occasionally present amplified music and need to be treated just for the event. The technology, permanently mounted, is being projected in various concert halls around the world and is being installed in the new Dubai Opera and in a new Cultural Center in Kuwait during spring 2016. This paper presents the authors' research as well as the technology showing applications in dissimilarly sized venues, including on/off measurements of reverberation time versus frequency.

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1. INTRODUCTION

In the JASA article *Suitable Reverberation Times for Halls for Rock and Pop Music* (1) it was statistically proven, based on questionnaire responses correlated with objective acoustic measurements in relevant halls, that what acoustically distinguishes the best from the less well-liked halls for pop and rock music is a shorter reverberation time in the 63, 125 and 250 Hz octave bands. Classical music, such as opera, chamber and symphonic music on the other hand, calls for a longer reverberation times at low frequencies.

Many halls, in fact most halls nowadays, present a variety of musical styles including pop as well as classical genres. It is therefore advantageous if these halls can vary the reverberation times most importantly in the low frequency domain.

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2. ACOUSTICS FOR ROCK AND POP MUSIC

The fact that rock and pop music should be performed in halls with a very controlled low frequency reverberation time is actually not surprising. It has also been pointed out by other authors (8,9). Firstly, a pop or rock concert is at least as loud and rhythmically active in the 63 Hz to 250 Hz bands as at higher frequencies.

Secondly, loudspeakers focus mid- and high-frequency sound while emitting LF sound much more widely out into the hall leading to reverberation if not absorbed. The so called *critical distance*, $r_{,cr,}$ at which the undefined reverberant sound is as loud as the direct sound was developed further in reference (7) and is given by equation (1):

$$r_{,cr} = \sqrt{\frac{Q\,V}{100\,\pi\,T\,(1-\alpha')\,N}} \tag{1}$$

Where Q is the directivity of the sound source at a given frequency, V is the volume of the room, T is the reverberation time of the room at a given frequency, a' is the average absorption coefficient of the room at a given frequency and N is number of discrete loudspeaker clusters. At a given frequency band, further away from the speakers than this distance, the sound level of the reverberant sound is louder than the direct sound. It is inherent from the equation that since Q is close to 1 at low frequencies a big share of audiences will suffer from reverberant, undefined low frequency sound if not the reverberation time here is tamed. The directivity at higher frequencies can easily be 10 and it is unlikely that the reverberation time of a room is a factor of 10 higher at high frequencies than at low.

Seen in that light, it is at least plausible, that the reverberation time in an empty room for amplified music can be accepted longer at high frequencies than at low and that the critical distance will still be shortest in the bass domain.

Thirdly, an audience absorbs 4-6 times more mid-high frequency sound than bass. If the loudspeakers are correctly aimed towards the audience the combined effect of a higher Q and a lower reverberation time by itself will advantageously control the critical distance at mid-high frequencies. In reference (1) the recommended reverberation time as a function of hall volume was set forth for rock and pop, directly deducted from the questionnaire results (Figure 1). Further, studies by the author lead to proposed acceptable tolerances of recommendable T30 in halls without audience in reference (3) (Figure 2).

Due to the punchy, boomy nature of the 125 Hz band and to the fact that our hearing does not roll off as fast in this band with the decay of sound as in the 63 Hz band due to a lower threshold of hearing etc., the 125 Hz band is probably the single most important octave band to control. This is also what the author and his colleagues have encountered at concerts. It seems that reverberant 125 Hz octave band sound unfortunately is a good and dominant masker.

Also in reference (1) it was found that there was a tendency, that sound engineers preferred an overall very short T30, but musicians preferred a somewhat longer reverberation time. One reason for this is probably that musicians enjoy a sensation of being *enveloped* in sound and of "*togetherness*" with each other and the audience while sound engineers in a quite dead room often enjoy the higher degree of control over their out-board gear including artificial reverberation tools.

It is believed, but not proven, that the audience also has a desire for a sense of *envelopment* since they are not attending live concerts to solely experience a high fidelity sound quality adventure, but rather a good sounding social event. To achieve this, a certain level of reverberant sound at live pop and rock concerts is required, but evidently according to the above, *not* at low frequencies. Hence a design goal for pop and rock halls could be to allow for an amount of higher pitched reflections for a sensation of envelopment. In big halls such as sports arenas, extremely precise speaker coverage for all audiences is needed. Recommendations for such spaces are found in the author's book on Springer Verlag reference (6).

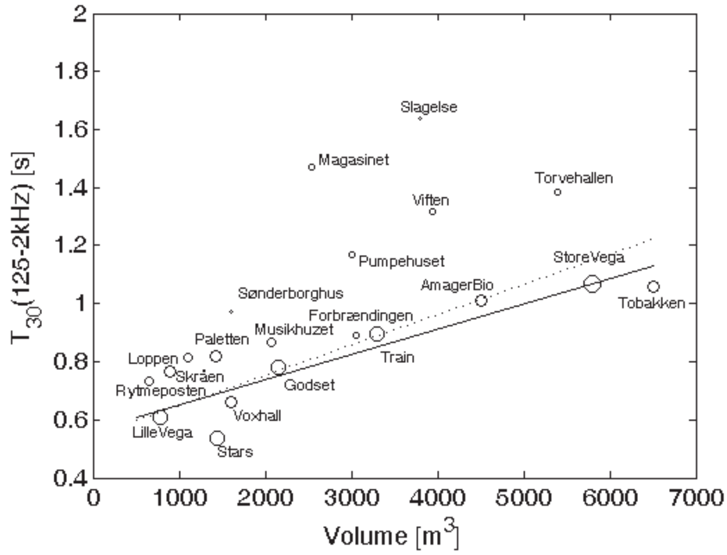

Figure 1 – Recommended value of T_{30} as a function of hall volume in small to medium sized venues

In brief, in an empty hall for pop music, T30 in the 125 Hz band should be determined after Fig. 1 while the reverberation time at other octave bands should be within the tolerance field shown in Fig. 2.

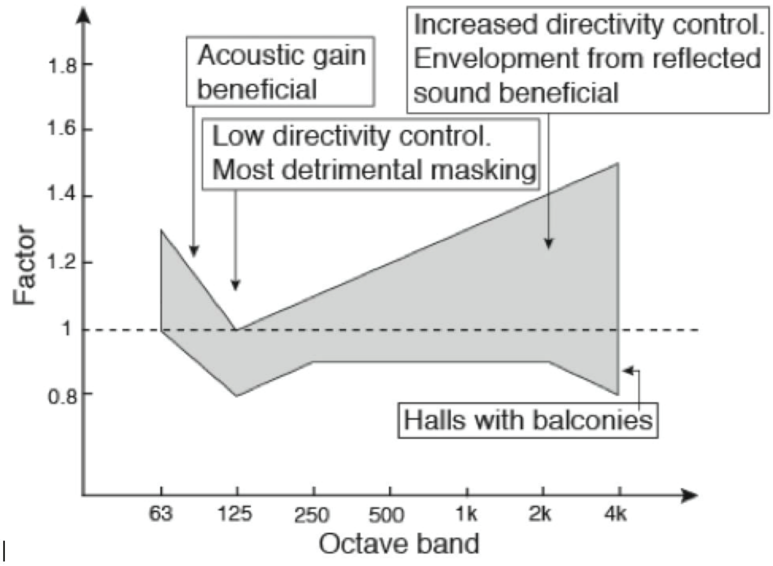

Figure 2 – Tolerance field for T_{30}. Factor 1 corresponds to the value found in Figure 1

3. INFLATABLE MEMBRANE ABSORBER TECHNOLOGY

From our knowledge that a low T30 at low frequencies is required for amplified music while the need for "warmth" at classical music demands a higher value of low frequency T30, attaining a high absorption coefficient over a broad spectrum including lower frequencies was one aim in the development of a new mobile and variable sound absorber. The basic technology of *inflated plastic membranes* as means for lowering the reverberation time in venues was presented in reference (2). The absorption features of such an inflated absorber are given by its dimensions, shape, material-weight per area, material damping properties and the pressure which to some degree determines the stiffness of the membrane, etc.

Since the plastic used in the practical embodiment of the technology is extremely thin and light, absorbers are mobile, and can be installed temporarily in any venue to lower the reverberation time in the most crucial frequency bands. The material used is flame retardant and complies with the required safety standards in Europe, the USA etc.: B,s1,d0, US NFPA 701, ASTM E 84 etc. and therefore no special permission is needed to use it publically at concerts. It is a specially engineered plastic with a high degree of inner damping.

3.1 Permanently installed on/off system for variable acoustics

The first measurements on an embodiment of the technology were presented in reference (3). The technology enables a practical way to achieve enough absorption variability when installed in the ceiling of a hall to make it possible, for example, to present both chamber music and rock concerts in the same venue both with favourable acoustics. The product is installed permanently for ON/OFF use as seen in Figure 3. The figure implicates how any number of rows can be activated to reach a desired reverberation time. In the off position the product has close to no affect on the reverberation time of the venue as seen in Fig. 4 showing the absorption coefficient in the on and off states.

The absorbers are 1,15 m of height and are attached to tracks mounted flush to the ceiling since they contract some 10% when inflated. They may be drawn to one side when not in use. All absorbers may be connected to a common fan placed in the hall or in another room. It takes approx. 6 min. before the absorbers are fully inflated after the push of a wall-mounted on/off switch. A control unit, that ensures maximum absorption at all times, automatically surveys the air pressure on the system. A lowered acoustically transparent ceiling can be mounted underneath the absorbers for aesthetic or utility purposes and may include attachment of lighting, fire sprinklers etc. Low- and mid- frequency sound energy is absorbed by this new technology with an absorption coefficient of some 0,5 over the entire ceiling area (Fig. 3, 4) w. a spacing of baffles of app. 75 cm center-to-center.

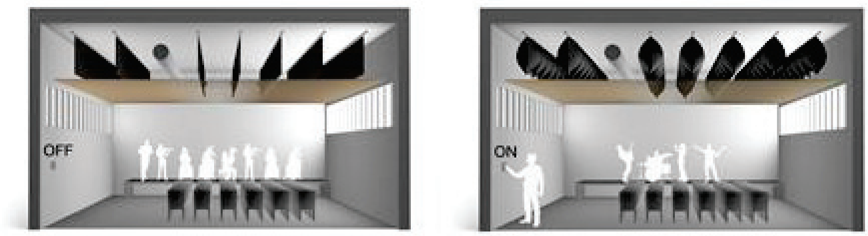

Figure 3 – A number of absorber-rows are mounted in the ceiling around fire sprinklers, ventilation ducts etc. For maximum reverberation time no absorbers are inflated. At pop and rock concerts all absorbers are activated by pushing an All On button. A third button activates only a portion of the absorbers for a reverberation time in between extremes.

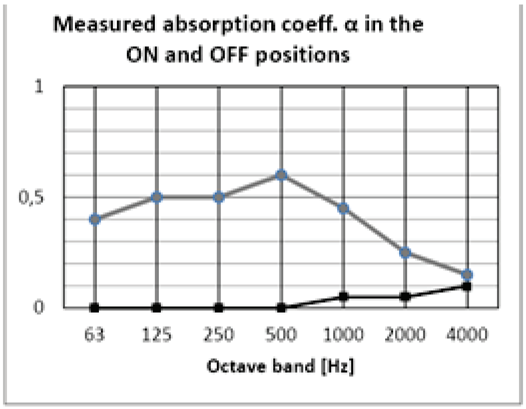

Figure 4 – Mix of three certified measurements of alpha. Two in rev. chamber (EU and USA) and one measurement based on the result seen in Fig 5. Spacing between absorbers center-center: 75 cm.

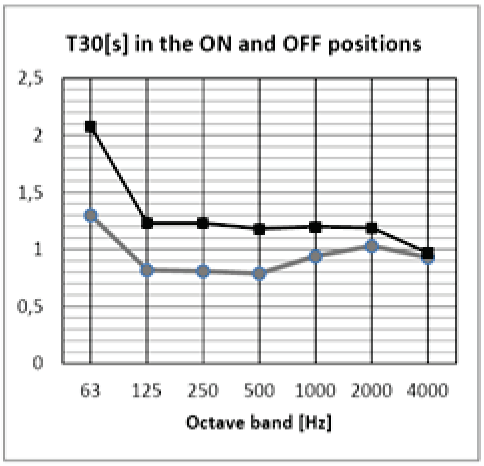

Figure 5 – Certified measurements of T30 in a Danish music conservatory. System in ON and OFF positions, one absorber row per only130 cm. corresponding to a difference of alpha of app. 0,37.

3.2 Temporarily placed mobile absorbers

Since the plastic used for the absorbers is extremely thin and light, they are mobile, easily handled and may be installed temporarily in any venue to lower the reverberation time in the fundamental, and therefore most crucial, frequency bands of musical instruments: 63-1k Hz. This mobile version weighs less than 1,4 kg/meter length and has a much larger diameter of app. 1,5 m when inflated compared to the smaller permanently installed baffles. The reasons for this bigger size are numerous and include a lowering of resonance frequency and a wider half power bandwidth whereby the tubes are less dependable on being placed in immediate proximity to a sound-reflecting surface for LF efficiency. Since the sound pressure is greater close to reflecting surfaces a higher alpha is still obtained here though. These bigger dimensions also ensure that larger areas can be covered reasonably fast, and that packaging after use is easier handled. To some extend certain “unwanted” sections of a hall or arena can be sonically detached from the rest of the venue placing the tubes close together somewhat lowering hall volume and thereby the reverberation time in the part of the hall where the concert takes place. Also, a certain effect of scattering of the sound field is achieved helping to reduce RT further. Each tube can be either pre-inflated or have a dedicated, demountable micro fan attached. The latter ensures that tubes can´t deflate. One central fan may also supply all tubes interconnected with hoses. These bigger absorbers can also be mounted permanently in for instance sports arenas and be used for variability of the reverberation time to be for instance long for loudly sounding sporting events and short for defined sounding concerts.

Absorbers are mounted vertically with simple straps to trusses or horizontally and may thereafter be self-inflating as mentioned. 3 cases of use of this new technology, w. absorption properties shown in Fig. 6, in sound reinforcement applications are mentioned in the following.

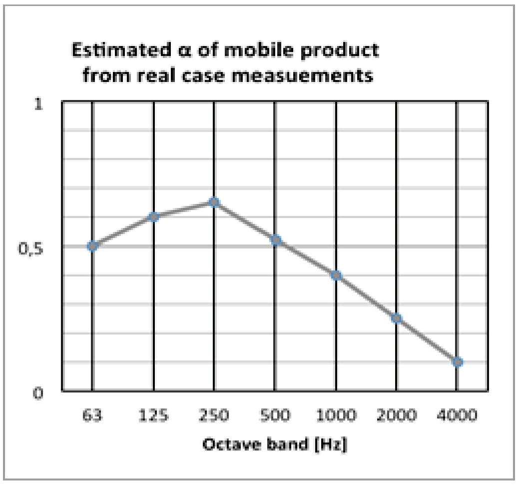

Figure 6 – Absorption coefficient, alpha, of mobile technology mounted as close as possible. Estimated from real case measurements; absorption effect only.

3.2.1 Case 1

Some 7.000 m2 of these patented, mobile sound absorbers were used in a 700.000 m3 former shipyard for the Eurovision Song Contest 2014 both horizontally and vertically mounted (Fig. 7 and 8). The empty space had a reverberation time of 11-13 sec in the 63-250 Hz interval. This was reduced to less than 4 s, even before the audience arrived (Fig. 9). Double layer molton fabric was used over vast areas on walls too. It could not be determined what precise effect the inflated membranes had but the acoustic consultant, Eddy Bøgh Brixen, was very pleased and got a better result than calculated, using an alpha value of 0,5 at low frequencies on the tubes. The reason is probably partly due to scattering and the partially isolation of a portion of the space. There was an app. 60-80 cm air-gap between the inflated tubes. The 7.000 m2 projected area, used at the ESC 2014 were fitted into 20 large flight cases when deflated after use.

Figure 7 – Horizontal tubes, 50 m, ESC 2014

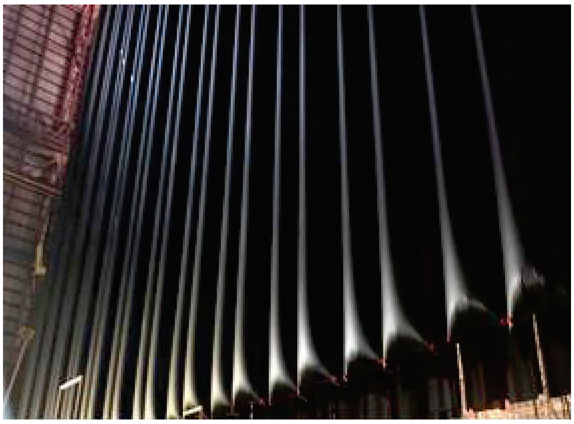

Figure 8 – Vertically mounted 35 m tubes, ESC 2014

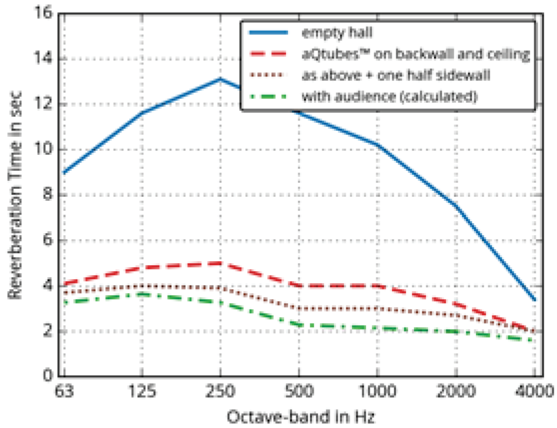

Figure 9 – Upper line indicates RT in empty space. Middle and lower line: tubes included in hall. ESC 2014

3.2.2 Case 2

One of the most successful bands these days is British/Irish boy-band One Direction. They had 55.000 audiences attending each of two concerts at Amsterdam Arena in June 2014. This arena was one of the first to be designed with the possibility of opening a (glass) roof. Due to noise problems the roof had to be closed at the concerts leading to reverberation times of considerable length also at low frequencies.

Acoustic consultant assigned to the job, P. van der Geer, took the approach of using the tubes as a combined absorber/diffusor/insulator with regards to the large volume between the glass-roof and the tubes. Only half of the open surface towards the roof (the one furthest away from stage) was treated as seen on Fig. 10.

Figure 10 – Horizontally mounted 35 m tubes, *One Direction* concerts, Amsterdam Arena 2014

Figure 11 – Vertically mounted 25 m tubes, *One Direction* concerts, Amsterdam Arena 2014

Further, at Amsterdam Arena, van der Geer took the same approach regarding the large empty volume behind stage (Fig. 11). Even when using cardioid sub speaker arrays a lot of bass sound still propagates rear of the speakers. The total projected surface area of tubes were app. 3300 m^2. Calculating what impact this amount of tubes would have in an enormous volume like Amsterdam Arena with app. 1,2 mill m^3, one gets to a quite little number. But as for ESC 2014 much higher absorption coefficients were encountered reducing RT by some 25% (Fig.12) probably due to the combined effect of not only absorption, but also diffusion and an effect of volume isolation. It must be noted that the measurement positions of RT in the treated hall took place on the floor below the tubes, rear in the hall at the sound engineers position.

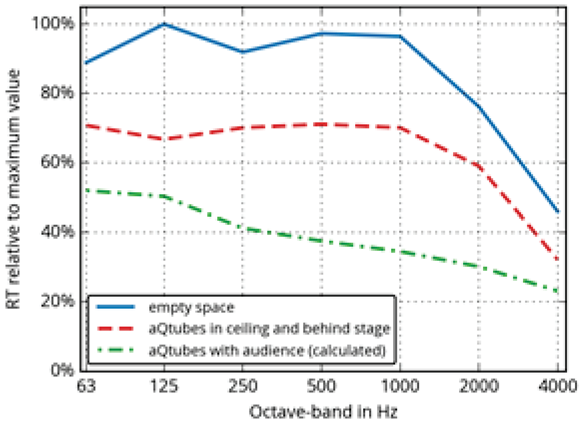

Figure 12 – Upper line indicates RT in empty space. In % due to discretion. Middle and lower line: tubes included. *One Direction* concerts, Amsterdam Arena 2014

3.2.3 Case 3

Legendary German electronic band, Kraftwerk, played 8 shows in January 2015 in the just as iconic Neue Nationalgalerie by famous Mies van der Rohe (1968). Production manager Winfried Blank had measured the acoustics in the beautiful 50x50x8 m^3 space on beforehand and had found a quite long RT also at lower frequencies (Fig. 15). He and acoustician, professor, Dr. Ing. Anselm Goertz took the decision to place 22 7 m high mobile tubes all along the back wall opposite stage (Fig. 13). And also to mount 3 35 m horizontal tubes in the high sound-pressure zone junctions between ceiling and wall (Fig. 14). All absorbers were placed in immediate proximity to sound reflecting surfaces and there is therefor no effect in this case of space-isolation. One layer of molton curtain was placed in front of back-wall tubes. Achieved reduction of $RT_{63\text{-}250}$: 30-50% (Fig. 15) -a very acceptable result indeed.

Figure 13 – Vertically mounted 7 m tubes, *Kraftwerk* concerts, Neue Nationalgalerie, Berlin 2015

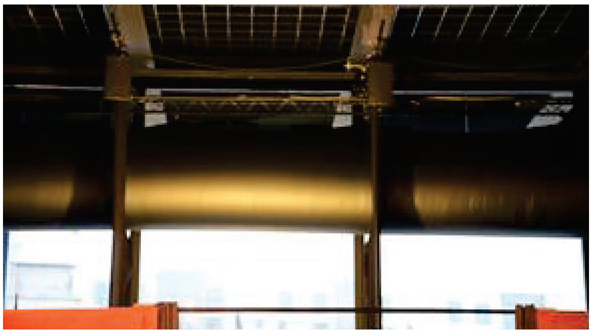

Figure 14 – As any other membrane absorber, the tube is most effective in high sound-pressure zones. *Kraftwerk* concerts, Neue Nationalgalerie, Berlin 2015

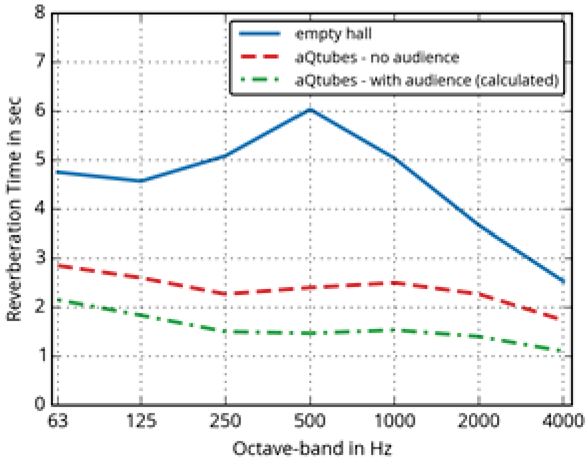

Figure 15 – Upper line indicates RT in empty space. Middle line: tubes included in hall. Lower line: calculated RT w. tubes and audience. Neue Nationalgalerie, Berlin 2015

4. CONCLUSIONS

The inventor of the technology and author of this paper is proud to be able to conclude, after more than 10 years x 365 days of development, research, fund raising, trial and error etc. that now there is a technology that can fix the most common and crucial acoustic problem at amplified music concerts. If the will is there, there is now a solution. The technology has proven even more efficient than expected, is reasonably easy to mount and takes up little space for transportation and storage. Multipurpose halls in Dubai, Kuwait, Korea, Germany, Finland, Denmark and Norway etc. are now adapting the on/off system for permanent installation, and planned live concerts in the coming months are being equipped with the mobile technology even for just single events. The technology is patented reference (5). Further, recommendations that ensure the best possible acoustics and thereby sound for amplified music concerts have been set forth reference (6). To the best of his ability, the author has tried to help enhancing sound quality at reinforced music concerts

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