Prototype 6

Year	2015-19
Considered in Prototype	6
Action	
1. Playing position	
2. Keyboard: appearance and feel	
3. Pulley and string system	Yes
4. Key pivot point to damper coupling	Yes
5. Key range	
6. Harmonic damping	
7. Minimal noise	Yes
8. Integrated amplification	Yes
9. Playing space on the string surface	Yes
10. String tuning and range	Yes
11. Access for maintenance	Yes
Harp	
12. String distinction	Yes
13. Tuning mechanisms	Yes
14. Top plate	Yes
15. Depth and volume of the resonating chamber	Yes
16. Optimised coupling of bridge and top plate	Yes

No	Not considered in this prototype
Yes	Actively considered
Yes	Working, but further optimisation possible
	Parameter considered optimised or range understood

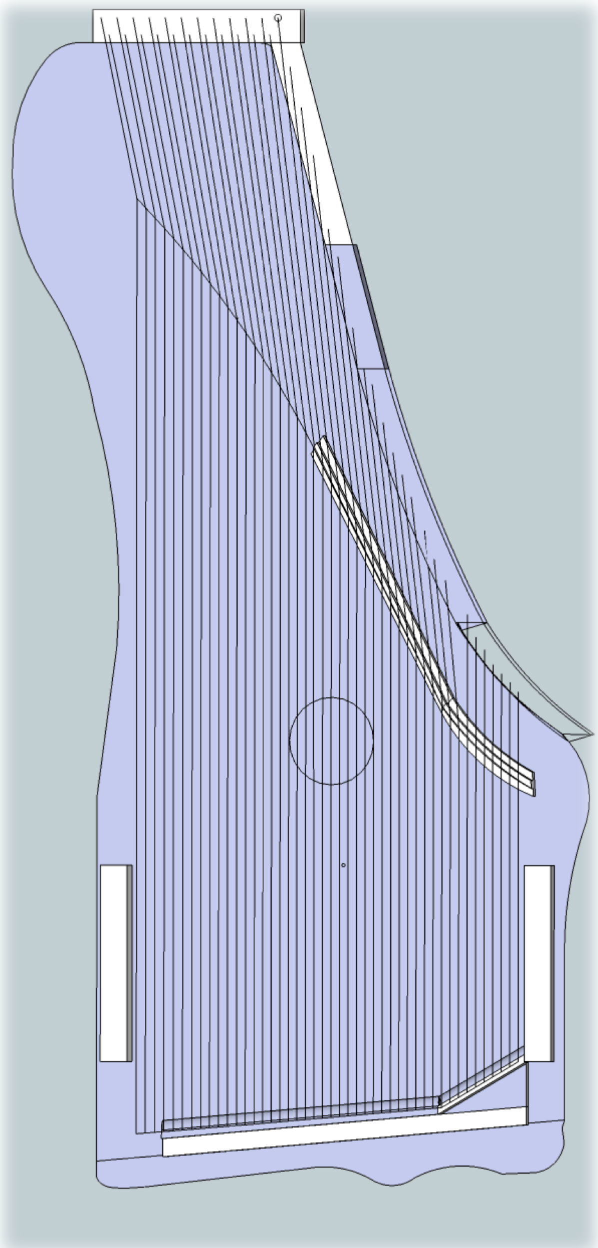

Figure 1. Projection of prototype 6 shape and assessment against design criteria

Prototype six remains purely at the planning stage although a considerable amount of planning has now taken place – I consider that all of the problems have been addressed. The most significant change is that it is certain that this prototype will be based on a bespoke harp, and that this is likely to be somewhat different to a traditional autoharp shape.

In the spring of 2013 I arranged a meeting and consultation with another luthier; Tony Johnson. Tony specialises in making lutes including a very complicated 13-course swan-neck lute. Though a very different type of string array, this instrument is large enough that it encounters similar problems in some respects. There were two purposes to this consultation: firstly, I wanted some tuition in the hand tools that are part of the basic training of the craft. Whilst my self-taught skills had improved markedly, I still felt that I lacked some of the basic experience in chisel and carving techniques. In fact a good deal of this part of the session focussed on sharpening techniques (the importance of which I had previously missed), and this proved extremely helpful to the subsequent build of prototype 5. Secondly, with a view to the planning of prototype 6, I wanted another opinion on the acoustic design of the autoharp body and how it might be improved. Tony had not even heard of an autoharp when I spoke with him initially on the phone, but agreed to take a look at the instrument before our consultation.

I took along prototype 3 to the consultation, together with my 3d renderings, and asked Tony his opinion on the acoustic design of the harp. My understanding had deepened considerably in the time since the initial consultation with Alec Anness, but overall I still felt similarly about many of the issues.

I had, by now, through both practice and research, understood the principle of arched and radiused (crown) top plates. Many internet sources provided information, giving a better picture of the techniques involved in producing them, and these techniques (and results) display considerable variety even within individual instrument species. Resources such as the Bilhuber (Steinway soundboard) patent of 1937 (Bilhuber, 1936), taught me how radius principles can be applied to a large array of strings, and to the particular shape of top plate that results. I realised that Alec applied either a compound (crown) or an arched curve to his top plate in his harp designs, which contributes to the much richer quality that they produce over commercial harps, but in other ways Alec's harps, quite deliberately, conform to the traditional autoharp design.

Guitar makers stress the importance of a large area behind the bridge in order to allow formation of a well-rounded bass. Even on smaller, travel guitars the bridge is almost invariably located on the soundboard itself, with a significant amount of space surrounding it (Howman, 2012). Talking to a trained luthier, who was clearly seeing the traditional autoharp instrument for the first time, was most refreshing. Tony first observed that the bridging on the Schmidt harp was to the frame at both toe and dead end, which would not transfer vibrations from bridge to top plate effectively;

there was no noticeable arching or crown shaping. In addition, he noted that the bass strings were too short, the cavity probably did not have enough volume (though this last could be deceptive, and should be calculated) and lastly, that he felt that the sound hole was in the wrong place. All of these excepting the placement of the sound hole (which was a surprise), were observations that confirmed my thinking and planning towards prototype 6.

Tony's initial thinking was that bridging over the soundboard could best be achieved at the dead end of the instrument — a proposal to which I was highly resistant because it would change the shape of the dead end completely and therefore the playing position. We talked around the issues for some time and the conclusion was that I should seek a design which incorporated all these ideas — but particularly that of allowing at least 2 inches on all sides of the bass bridging area. The design shown at the beginning of this section is the result. The string lengths are recalculated — slightly differently from the string distinction projection in chapter three, but still using guitar string gauges, to allow for a continuous tapering of the string surface down the length of the instrument. Bridging on the top plate is formulated at the toe end of the instrument where a new rounded lobe surrounding the bass area is created. This is similar in principle to the bridging found in the Millington/Young instrument, though extended. Separate radius points could be taken from the centre point of the new bass lobe, and the centre point of the main harp body, such that the top plate would have a double crown, or perhaps a crown around the bass area and a simple arch through the main body of the harp. Extra volume is created by offsetting the angle of the bass plate with respect to the top plate (a wedge shape), such that the cavity becomes deeper towards the toe end of the instrument.

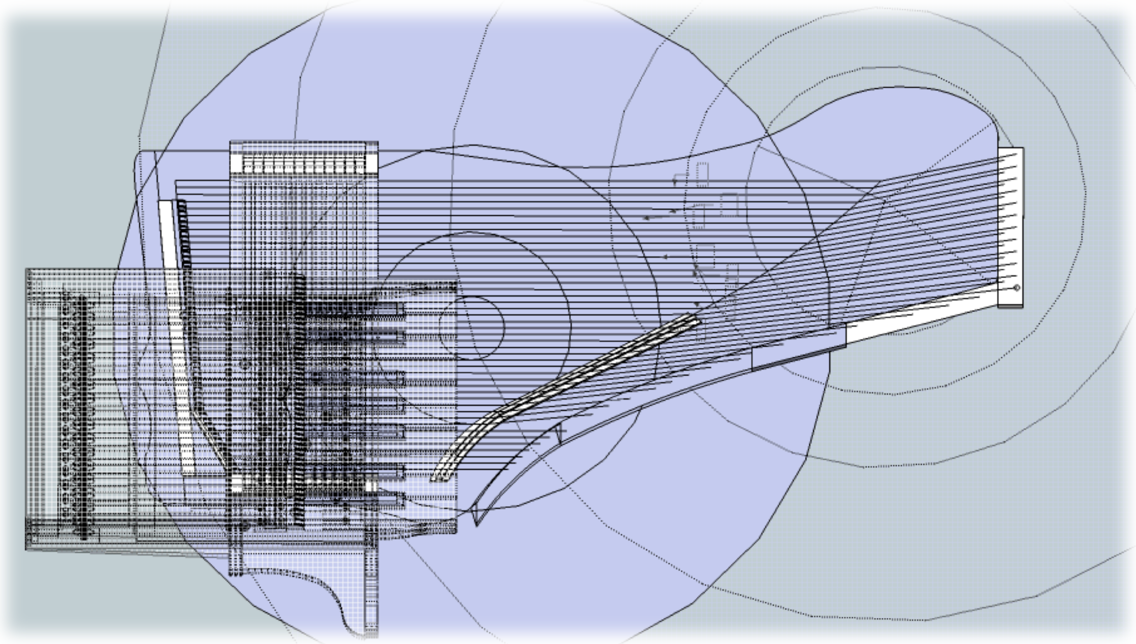

Figure 2. Possible radius points for prototype 6

All changes are designed from the perspective of improving the sound without altering the playing position. These two selective pressures result in an interesting aesthetic shape, very different to the autoharp. It is suited to the seated position of the Raph, but perhaps would not be suited to the slightly more upright autoharp position.

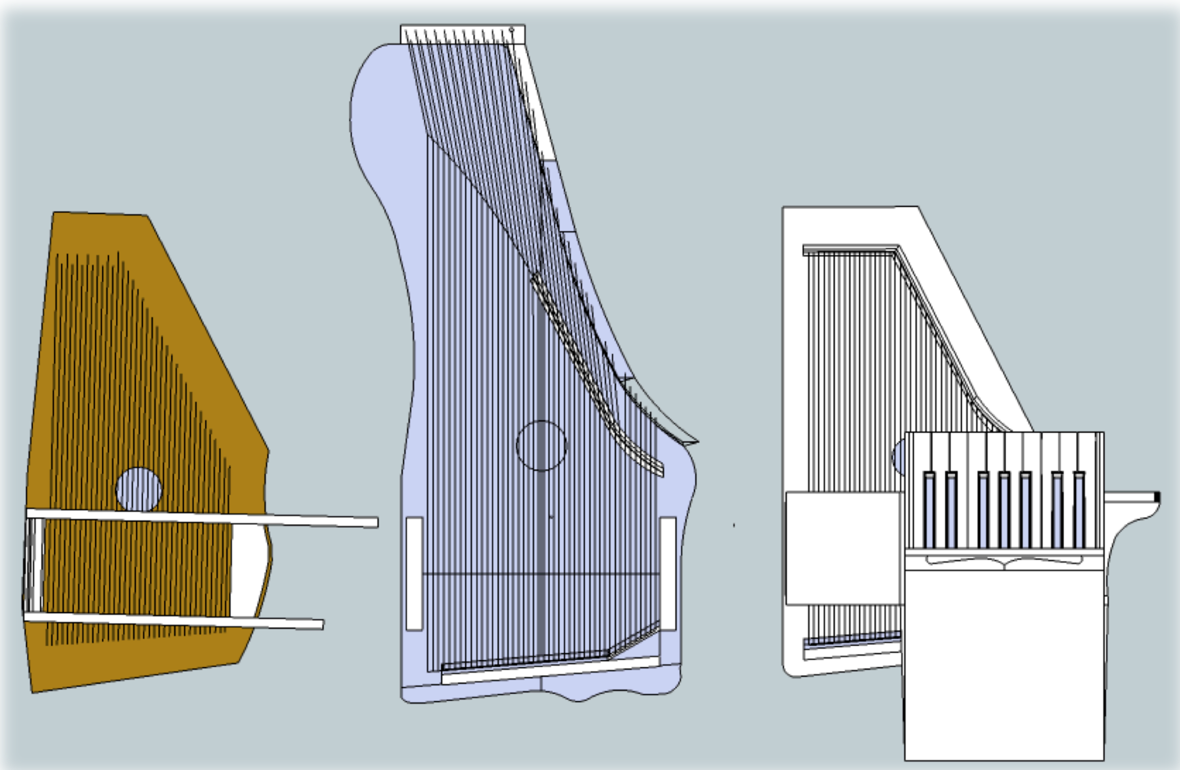

Figure 3. Overall size and shapes compared: left: Schmidt (prototype 3), middle: projection for prototype 6, right: prototype 5

An idea of the overall shape does not signal workshop readiness however. To illustrate the kind of unforeseen problem that might arise: at the meeting of October 14, I challenged Alec Anness about the issue of bridge connection to the top plate once again. Perhaps because I was clearly better informed and formulated my questions much more precisely Alec answered readily, and the answers were very helpful. It turns out that Alec's bridges do overhang the top plate — as far as possible, but that a limiting factor (and a serious consideration when formulating method for prototype 6) was that the bridge pins needed to be hammered into the frame in order to ensure that there was no subsequent movement of the bridge as a result of string tension from different directions (as the angle turns from bridge to zither pins). If the angle of each string is perfectly straight as it exits the bridge to the tensioning device, then there is no problem. In practice, this is quite difficult to achieve, particularly if an attempt is made to integrate geared machine heads as opposed to zither pins. It would also be possible to support the bridge from underneath the soundboard through a brace, which would place less pressure on this measurement.

The project has required a significant re-tooling before progress can be made. The radius template needs to be designed and rendered, and the means of producing the harp frame must be finalised. Using a radius for a large notional sphere (guitars commonly employ within a range of 25–40ft), a bespoke radius template may be rendered using routing techniques, or by using 2 MDF or plywood sheets at a thickness which is stable, but will bend under force. Separation distances are calculated between the two sheets and spacers are added. This technique also gives the ability to produce more complex non-circular shapes, which conform more closely to harp top-plate shape.

The means of rendering the new shaped frame itself requires careful planning. The new curvature, particularly on the bass side, probably calls for the application of a either bending or carving technique applied to the frame rather than simple frame spars. Autoharp frames are rendered from four lengths of solid stock, and this provides a suitably rigid frame for the large number of strings, and also includes space for zither tuning pins. Since the shape is essentially rectangular, no bending techniques are necessary, and as far as I am aware have never been part of the fashioning process for autoharps. In contrast, guitar side plates are bent into shape through heat and steam, and are as little as 2mm thick (to around 4mm common for jumbo guitars). Such minimal depth would not be suitable for a harp, however, given the increased depth at the toe end (due to the wedge shape) there is potential for thinning, and also the application of bending techniques. Traditional guitar side plate bending techniques would probably be ineffective given the frame thickness required. However, I have been experimenting with a technique from furniture making where the spar to be bent is placed in a wood chamber and subjected to steam continuously for around three quarters of an hour, to the point where the wood is completely saturated. The spar is then highly pliable for around 30 seconds on removal and can easily be bent into shape and clamped. The clamping time is considerable — the furniture demonstrations suggest around 2 weeks. The wood suggested is beech — renowned for its bending properties. This would be a suitable material for the frame and is sometimes used in guitar side plates.

Once frame and top and bottom plates are rendered, a further jig is necessary to allow effective clamping for a permanent and airtight fix. There is considerable variation in the way that guitar makers achieve this; from multiple clamping to bespoke jigs where flexible rods can be placed at precise points under pressure from a ceiling plate.

Access to the keyboard for maintenance was found to be significantly worse in prototype 5 than prototype 3b. This was mainly caused by changes to the keyboard pulley wheel system which disallowed the keyboard system to be slid forward and stood upright. However the changes at this point did result in other general improvements – tension was maintained throughout the pulley wheel system. I propose therefore, to change the means of access to the keyboard and pulley system entirely, by fixing both systems completely to the bass such that they are relatively immoveable and that the keyboard box is designed to be quickly removed – it is simply a cover to this system. This would allow complete access to all systems without having to release any working part in order to do so.

The search for improvements to pulley wheels themselves has continued. Generally, these much are easier to source than when prototyping on this project began and there are greater varieties. The pulley wheels shown in figure 4 for example, are the required size but based on bearings which would provide a significant improvement on the friction within the system, potentially significantly improving the feel of the keyboard. A disadvantage is that they will add weight to the system as a whole, and their implementation needs to be balanced between these two selective pressures.

Figure 4. Possible replacement pulley wheels with integrated bearings

The banjo friction pins, for which I had high hopes, but which caused so much trouble prototype 5, are to be replaced by another mechanism that I have sourced from Portuguese guitar design called a Preston, or Watch-key tuner.
The picture below shows home crafted version of this mechanism, which is simply a nut and bolt where the nut is constrained from turning. As the bolt, held between two fixed points, is turned; the nut must travel up or down it. The string (in this case, the pulley string) is attached to the nut.

Figure 5. Preston tuner set for a Portuguese guitar

Figure 6. Preston tuner set for a banjo with a distinctly hand-crafted flavour

An essential preparation for prototype 6 and all prototypes to be built subsequent to PhD completion in 2015 was that a dedicated workshop be built to accommodate the retooling that is necessary. Previous to this the workshop space at home was limited

Figure 7. New workshop 2017 - 19

to have a garage – and in a space uneasily shared with studio. The workshop has been completed using 70% recycled materials. Landscaping began in 2017 and the workshop was completed in 2019. Its 3.5x3.5 footprint affords plenty of space to undertake the increased complexity of the next stages of this project. An outside covered space also offers a space to build a large steam chamber. Assuming that I have identified all the significant issues, I would estimate that the task of building a harp body is roughly comparable in complexity to that of the keyboard action — possibly marginally less so once the re-tooling is complete.

Overview of Design Criteria Within the Prototype Series

Year	2007	2008	2010	2011	2012	2014	
Considered in Prototype	1	2	3a	3b	4 (virtual)	5	6
Action							
1. Playing position	Yes	Yes	Yes	Yes			
2. Keyboard: appearance and feel	No	Yes	Yes	Yes	Yes	Yes	
3. Pulley and string system	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4. Key pivot point to damper coupling	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5. Key range	Yes	Yes	Yes	Yes			
6. Harmonic damping	No	No	Yes				
7. Minimal noise	No	No	No	No	Yes	Yes	Yes
8. Integrated amplification	No	No	No	No	No	Yes	Yes
9. Playing space on the string surface	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10. String tuning and range	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11. Access for maintenance	No	No	Yes	Yes	Yes	Yes	Yes
Harp							
12. String distinction	No	No	Yes	Yes	No	No	Yes
13. Tuning mechanisms	No	No	No	No	No	Yes	Yes
14. Top plate	No	No	No	No	No	Yes	Yes
15. Depth and volume of the resonating chamber	No	No	No	No	No	Yes	Yes
16. Optimised coupling of bridge and top plate	No	No	No	No	No	Yes	Yes

No	Not considered in this prototype
Yes	Actively considered
Yes	Working, but further optimisation possible
	Parameter considered optimised or range understood

Figure 4.73. Overview of design criteria assessments within the prototype series as a whole

The table above considers progress on each of the design principles expressed as selective pressures through the prototype series as a whole. It shows a gradual increase in engagement with the entirety of the principles that reflects the practice as I experienced it. For the most part, the transitions move smoothly from red through amber to green. Exceptions are found in the harp body itself. Points are marked green in Alec Anness' harp, but return to amber (actively considered) as I begin to take over all of these processes.

String distinction remains a thorny issue. It was considered to some extent within prototype 3, but the addition of visual indications of strings only helped with tuning — it did not seem to me to aid string recognition within the array. In principle, there is no reason why the variable-spaced projection cited previously could not be married with the straight-strung projection proposed for prototype 6; but I would like some way to demonstrate that the gain would be significant as, unlike all other changes described this particular "improvement" is very difficult to test. Probably the most direct and objective method it would be to obtain feedback from other players, and bearing in mind that there are other, simpler solutions, (such as the Millington/Young solution of simply drawing a keyboard oriented against the strings) I am more inclined to plan for a retrofit of this method on an earlier prototype for testing, rather than allowing the issue of acoustic design change to become complicated by the separate issue of string distinction within prototype 6. Further, I am inclined, at least initially, to test the unusual guzheng strings described within the Context 1 report, and these provide string distinction through colour coding.

Returning to the keyboard action, another marginal issue is that of the sustain pedal. Many of the other inventors who have worked on this problem implement a means of lifting all the dampers simultaneously. I am attracted to this device, but remain hesitant as to its actual musical value. In the autumn of 2014 I began playing prototype 3 in the Adelphi Contemporary Music Group at the University of Salford, and it was this experience that finally persuaded me that it might be worth trying to implement this system. I remain unsure as to whether it will prove useful during engagement with tonal repertoire, but it would certainly be useful in achieving a freedom of engagement across the harp as a whole and would suit a particular brand of contemporary classical engagement within this ensemble. Again, the best way to implement this might be initially through a retrofit to either prototype 2 or 3, in order to test it, because the device will be quite imposing, and will certainly change the look of the instrument somewhat, and its overall musical value is yet to be demonstrated.

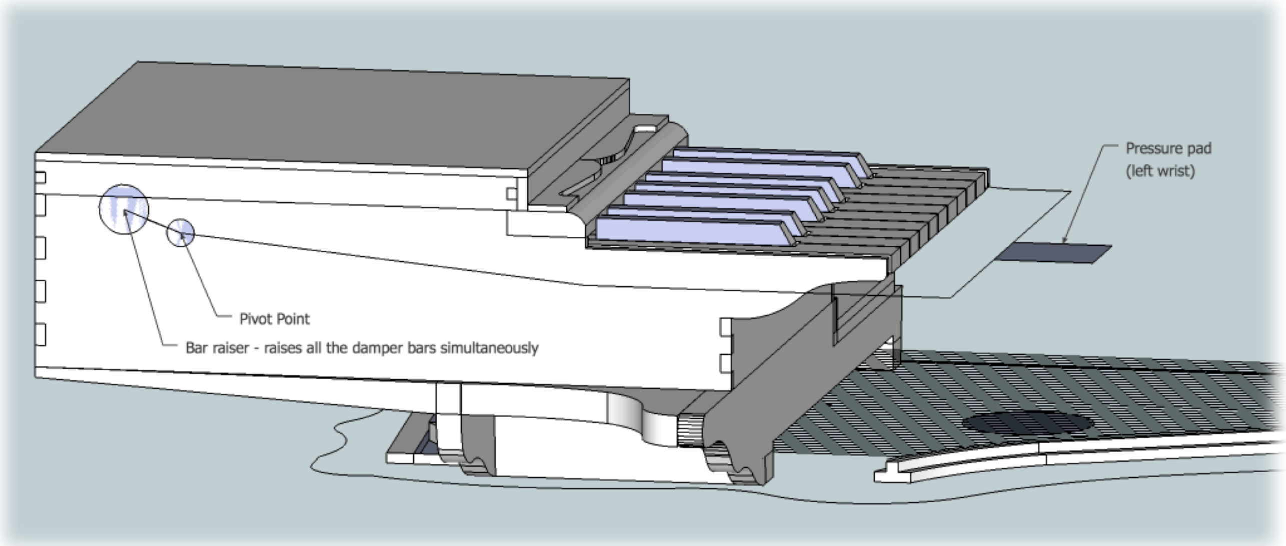

Figure 4.74. The principle of the sustain pedal – operated by the left wrist resulting in a bar which pushes all the dampers up simultaneously

Summary of Next Steps towards Prototype 6 – Summer 2019

Harp body

1. Finalise top plate design
2. Finalise arch and radius points – and produce the required jigs
3. Design and finalise plan for bracing across top plate (render radius template)
4. Design and finalise string tension devices (based on watch-key tuners)
5. Design and finalise harp frame, and harp frame method (render frame templates and clamping jig)
6. Render harp — tune and observe stability over time
7. Retro fit string distinction mechanisms to prototype 2 and test

Keyboard action

1. Retro fit sustain pedal to prototype 2 and test
2. Consider alternative redesigns of keyboard housing. Assess for comparable or better maintenance access, and more efficient build time

Works Cited

Bilhuber, P. H. (1936). *Patent No. 2070391.* USA.

Howman, D. (2012, March 28). *Making Guitars with a Physics Mind*. Retrieved July 2102 from Youtube: https://www.youtube.com/watch?v=o0FT2nsg0sQ