COBOD

Gantry versus robotic arm based 3D construction printers

The suitability of the gantry type 3D construction printer, which was used for printing The BOD – Europe's first 3D printed building.

AVAILABLE OPTIONS FOR 3D CONSTRUCTION PRINTERS

We believe there is fundamentally a choice to be made between a robot arm printer and a gantry type printer.

Generally speaking the robot printers have the advantage of being more mobile/movable than gantry printers and of being able to print certain prints due to the 6 axis movement that gantry printers would have difficulties with. Gantry printers on the other hand typically have cost and stability advantages, offers the ability to make larger prints and even print entire buildings in one go (as opposed to the more limited prints of robot printers and the robot printers need for printing single elements). Gantry printers also allow for non-continuous printing, which is needed when printing entire buildings, are far more easy to control and does not require highly skilled programmers.

Put shortly and perhaps a bit too simplistic: A robot printer is more suitable for “expert” operators (typically the robot supplier themselves) printing of single elements with high complexity and detail, while gantry printers are more suitable for more ordinary operators printing a larger variety of prints and for printing much larger structures, up to entire buildings.

In the below we will explain the above characteristics and issues in more detail.

PRINTABLE AREAS OF ROBOT AND GANTRY TYPE PRINTERS

We believe that one of main drawbacks of robot printers is the limited printable area, which they offer making it particularly difficult to use this type of printer for testing and experimentation.

The users of robot printer are practically forced to only print elements not entire structures/buildings. These two critical points, we will try to explain further below:

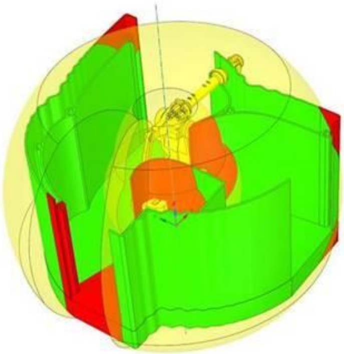
For robot printers the following is characteristic: The robot itself is rather large, the arm rather short and the robot needs a lot of clear space around it. This will severely limit the printable area that each robot printer has.

In the following images this point is illustrated. The illustrations below show the largest robot arm that can be found, the Fanuc M-2000i/A900L robot arm. The reach of the arm is 4683 mm. The robot arm can reach 330 degrees rotation. This results in a dead zone where the robot cannot reach, or in other words the robot can maximum print a piece of “pie” covering 330 degrees.

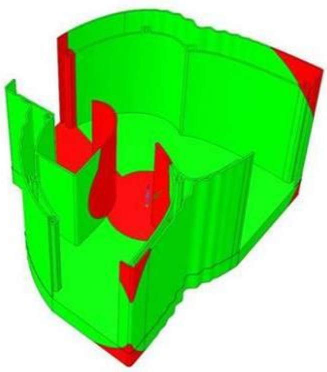
Thus, when using a robot printer, you cannot print 360 degrees around the robot, and in fact for most robot prints the robot is located in front of the printed area and actually only print a “pie” corresponding to around a maximum of 120 degrees due to problems with printing a wider “pie”. This severely limits the printable area of the robot printers.

Comparing such a robots printable area with the printing path for "The BOD" the following can be seen: If printing with a robot from one fixed location even the largest robot arm is hardly able to print a building, the size of The BOD (can print the green areas but cannot print the red/orange areas), and definitely not a lot more (the yellow circle), but the robot in addition takes up so much space that there's no room for the robot inside the print itself, meaning that certain parts of the inside cannot be printed (the orange area).

The above points are illustrated further in the following images. In the images below, the yellow doughnut is the reachable/printable area. The green is the part of the house that the robot can print, the red part is the part of the house that the robot cannot print.



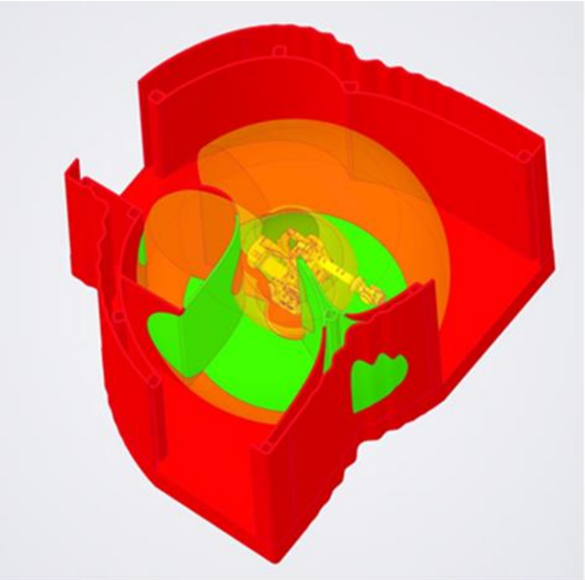
Printable area for the largest robot arm compared to The BOD building.



Printable area for the largest robot arm compared to The BOD building.

Printable area for the largest robot arm compared to The BOD building.

The shortcomings of robot printers in terms of reach when printing from one fixed point become even more clear, when it is investigated what a robot printer with an arm with a maximum 3 meter reach (which is typically what robot printer companies like Cybe and Xtreee offer) can print:



Printable area for a robot printer with a max 3 meter reach robot arm, typically supplied by robot printer suppliers

It is obvious that such a printer has a very, very limited printable area compared to the gantry printer we sued for The BOD.

One of the ways the robot printer manufacturers try to overcome this problem is to move the robot such that it prints from multiple fixed points or by making the robot mobile. This, however, also provide a lot of issues as will be explained below.

NOT ENTIRE STRUCTURES, BUT ELEMENTS PRINTING WITH ROBOT PRINTERS

In combination with the above issue of printable area another issue becomes relevant: With the robot type printers it is virtually impossible to build entire buildings in one go (due to the limited printable area), forcing a user to only print building structures that can be made up by several elements/sections made by the printer and assembled on site.

The printer can print the elements off-site or on site. Off-site has the advantage of the printer operating in a more controlled environment, but requires transport and assembly of the printed elements on-site. Such transport cannot be done before the printed elements have hardened enough to be able to handle the transport. This typically first occurs after several days.

On site printing of elements on the other hand removes the need for transport, but not the need for assembly and connection of the elements. Also, when printing elements on site the print does not occur in a fully controlled area as would be the case with off site element printing.

On site was the approach Cybe took when printing the laboratory in Dubai. Smaller elements where printed and then assembled on site, instead of the entire building in one go as was done when The BOD was erected.

Even if the printer because of tracks or wheels is movable, using a robot printer typically means that it is necessary to print each element entirely and then move the printer to print the next element (and creating the need for assembly/connections) due to the setting of the concrete. Thus a user typically cannot just print one layer of a first element (the reachable area of the robot from its first fixed position), move the printer to print the first layer of another element, and then come back and print further on the first element, as the first layer on this element would have set completely once returning to it, whereby layer two would not bind probably to layer 1.

Obviously, to overcome this problem the recipe of the concrete could be adjusted to allow for longer setting time, but even this does not remove the need to assuring that the robot is returning to the first element precisely at the right time, which with several movements of the printer (to enable a large print) will be very difficult to time. This is likely also the reason why a robot company like CyBe typically chooses to print each element entirely and then connect the elements.

To illustrate our points regarding the use of robot printers and the issues connected with the related element printing, we refer to the following video: https://www.youtube.com/watch?v=t_3U2UuiZgI

Notice that the building is being done by relatively small sections/elements and when the connection is being made between a new element/section being printed and the old/existing, there is no bonding between the new print and the old print. They are just touching each other, but not bonding, making it necessary afterwards somehow to connect them.

Also notice that in order to get close enough to print the new element/section up against the old element/section the print head must be “tilted” (not be straight up and down) leading to the generation of excess material, which one of the guys manually is removing (person in grey t-shirt, see screen shots below). This is a fundamental/structural “problem” of using a robot printer, and cannot really be improved going forward. Also, to assure that the new element/section is being made precisely where the previous element/section ended, the placing of the robot on the various fixed positions is extremely critical.

Print head tilting to reach the corner, needed due to sectional printing, but no bonding occurs between new and existing print

Person in grey t-shirt removing excess material due to tilting of print head

SOLID CONNECTIONS OF ELEMENTS NEEDED

Also printing elements means that solutions for the connection of the elements have to be found. Solutions that can live up to the building codes regarding moisture, insulation etc. Not an easy task.

Obviously the connection of elements is a well-known task within the precast concrete industry, but precast concrete elements are very different from 3D printed elements. When making precast concrete elements, these typically already contain the insulation and are prepared for the connections and therefore are much more suitable for connecting.

PRINT FILES/PROGRAMMING THE ROBOT TO PRINT/SOFTWARE

In addition to the above two critical issues, the following should also be considered:

A Robot arm is difficult to program, as the 6 Degrees of Freedom of the printer tends to get in the way of each other. Please consider the following robot arm programming tutorial on youtube: https://www.youtube.com/watch?v=zC5Z8eipbPc.

What should be noticed is how the operator needs to try and try again to make the robot not squeeze itself into a situation where it needs to twist the arm rapidly to unlock itself from a bad situation. In fact, the programmer fails to really find a good solution and in the end accepts a path that still has some twitches as he completes the tutorial.

To use a robot arm really requires an operator (robot programmer) that previously has been trained in robot handling (and programming). Thus, while a robot “programmer” would be preferable to have when a user is applying a robot printer, the bare minimum is a robot “operator” that at least can do some programming. For a multi-user situation this is really an issue to consider.

Also, as other companies involved in robot printing has mentioned, it is not so easy to come from an ordinary .stl file (that any of the architectural drawing programs like Autocad or similar can make) to a program code that can control the robot printer. In other words, to get from an architects drawings to the “print file” again a programmer is needed and the programmer has to program parts of the robot movements manually. It is difficult to estimate the time needed, but generally hours of programming would be needed.

Even if the robot printer suppliers have developed their own software for the file conversions (from .stl), such software solutions does not generally mean that all issues have been resolved and any architect file can just be converted to a print file without manual input for each print. Hence, typically even with such software solutions developed by the robot printer supplier, manual input in terms of robot programming is required. With the usage that Kamp C has in mind, this would indeed be something to consider.

We are only aware of one robot printer supplier that has developed inhouse software that supposedly can convert virtually any model file to a print file, but that software requires that the model is coming from Rhino (as opposed to any CAD drawing software), and the huge problem with that is that Rhino is not the type of software typically used by architects and engineers. So while using this software might overcome the biggest problems with the conversion from a model file to a print file, such software demands that the architects or engineers drawings made in traditional CAD programs, are made again using Rhino. This is not really productive and will only partially reduce the amount of manual work required for transforming the architect/engineers drawings to print files understandable for the robot printer.

The BOD gantry printer on the other hand uses "normal" 3D printer software which has been developed over 10 years as open source projects and has source code freely available so anybody is free to change it to meet their needs. We will supply the printer with a version of one such software (our own software) that we have optimized for preparing code specifically for our printer.

This software automatically converts the .stl into print files. As long as the .stl file is complete the software will automatically handle the conversion to the print file, without the need of a programmer. In that sense buying an operating a gantry type printer is much like buying and operating an Ultimaker.

On the other hand using a gantry type printer without the experience of having used a 3D printer before would also not be advisable. In that respect the gantry type printer is not so different from a robot type printer. The difference lies in that to become an experienced robot operator is much, much more difficult and demanding than to become experienced with 3D printing. It is simply more demanding to master the robot than to master the 3D printer.

In addition with 0,5 million 3D printers sold annually and 3d printers selling for prices as low as 200 euro, the experience with 3D printing is obviously much more common and easy to obtain than the experience with robots.

Our slicing software works with STL files, which is the de facto standard for 3D printers worldwide. Any CAD system can export STL files - or 99% of all. Our printer is compatible with any slicer that is normally used for FDM printers, but we do supply a special software (our own software) that we have developed to allow for more control and more precise slicing usable for the large scale printing that our construction printer can do.

CONTROLLING THE MATERIAL FLOW/HOPPER ALLOWS FOR NON-CONTINUOUS PRINTING

Finally, it should be noted that printing with a gantry type printer increases the possibility of controlling the material flow by applying a hopper above the print head. Due to the reservoir of materials in the hopper, the printer is not forced to only print continuously, as the outflow of materials can be stopped when the print head moves over areas where no print is supposed to happen, like we did when we printed The BOD, where we had no prints where the door and windows should be located. The auger in the hopper that pushes the materials out through the nozzle is simply turned off leading to no material exiting the nozzle, and instead the materials coming from the pump is just being accumulated in the hopper.

Without the use of a hopper, the printer is virtually forced to print continuously , making it impossible to print structures where certain parts are not supposed to be printed, for instance because a window has to be placed there. (In theory it should be possible to control the outflow of materials from the nozzle via the pump - located on the ground - but practical experience shows that it is not possible to do precisely enough due to the dynamics of the material and forces being applied).

The application of such a hopper is often not possible when using a robot arm and when hoppers are applied to robot printers, the print head becomes quite big and “clumsy”, adding even further challenges when preparing the printing path (as the big print head often will “bump” into previously made printed areas).

This is the reason why the majority of robot printers do not have a print head with a hopper and why virtually all prints made with robot arm printers are continuous prints, where the printhead prints continuously, without pause. If the videos of robot based prints are studied, it can clearly be seen that virtually all of these are made with a print path that just continues forever, where the printer is printing all the time without ever having to stop the print while passing over an area (a place for a window for instance), and then to start to print again when the area has been passed. The robot printers simply generally do not have this start/stop functionality due to the lack of the hopper/reservoir. This is a serious limitation to the types of prints that can be made with a robot printer and further increases the complexity of generating a clever print path.

This need of continuous printing when using robot printers also has other consequences: As the materials continue to pour out with the same speed/volume, if the movement speed is reduced at a certain area due to a difficult print, there will be excess material generated at that location leading to an uneven print (or that excess materials must be removed manually).

So for instance, when corners are being printed using a robot printer, it is very typical to reduce the speed of the movement, but as the amount of material being released from the nozzle is maintained, this is causing an excess of material to be generated in the corners.
(In the above mentioned video, if you study it carefully, you can see the excess materials in all corners, and it is especially visible at the corner in the front most to the right hand side of the picture).

Excess materials being placed around corners due to slowing down of the print speed at the corners

Person in black t-shirt removing excess material with spatula at point where the printer is printing a double corner (180 degree turn)

GANTRY PRINTERS CAN PRINT BOTH LARGER AND SMALLER BUILDINGS

Of course "larger" is relative - our current printer prints roughly 6,8 x 7,7 x 5,8 (WxDxH) meters.

Printing of storey high walls is not a problem, and even printing a two story high small building would also be possible.

GANTRY PRINTERS CAN ALSO PRINT COMPLEX, ARCHITECTURAL PARTS WITH A HIGH DEGREE OF DETAIL

Our printer can be controlled precisely in X, Y and Z directions and the extruder can run at variable speed allowing for slow and fast printing speeds (and even pausing when non-continuous printing is needed). For finer prints with high degree of detail, we would suggest a smaller nozzle and lower layer height. So this can be solved. Our nozzles are 3D printed which allows a lot of experimentation and flexibility.

However, please note that for finer prints the general challenge is how the material behaves, not what the printer can do, and there is still a lot of work to be done in materials development. Obviously, the more "mortar" like materials that is being used for the prints, as some of the robot printer suppliers have used, the finer the prints can be, but this type of material will generally not have the same strength as more traditional concrete type materials.

In general concrete as a material does not typically allow prints with a lot of overhangs - printing outside of what you just printed. This likely limitation we have not yet explored the limits of.

GANTRY PRINTERS ARE MOBILE AND CAN BE USED IN-SITU AS WELL AS OFF-SITE

Our printer can be moved. Obviously, it is more difficult to move a gantry printer tan a robot printer, but it actually only takes a maximum of 2 days to take the printer down and put it up in a new location. We expect that with more experience, we can reduce this to one day. We have already used our printer both for in-situ printing and off site printing in a factory environment.

GANTRY PRINTERS CAN PRINT WITH CONCRETE AS WELL AS MORTARS

Our BOD printer has printed everything we have offered it, including traditional "3d printing concrete" as well as recipes with a high content of recycled materials. We can print concrete type materials as well as mortar type materials.

Please note that due to the usage of materials with a size up to 8 mm, which we did when making The BOD, in our case we are really able to print a concrete type material, not just the mortar type material used by the robot printer suppliers. On the other hand when printing the finer mortar type materials, the prints become smoother and nicer in general, whereby we are saying that the usage of mortars is generally not a bad idea and can lead to nice prints, but the user should be aware that this means that the strength and durability of the print is limited.