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1 3D printing in the Construction Industry: a review

2 Abstract

3 3D printing (3Dp) has long been used in the manufacturing sector as a way to automate, accelerate
4 production and reduce waste materials. It is able to build a wide variety of objects if the necessary
5 specifications are provided to the printer and no problems are presented by the limited range of
6 materials available. With 3Dp becoming cheaper, more reliable and, as a result, more prevalent in
7 the world at large, it may soon make inroads into the construction industry. Little is known however,
8 of 3Dp in current use the construction industry and its potential for the future and this paper seeks
9 to rectify this situation by providing a review of the relevant literature. In doing this, the three main
10 3Dp methods of contour crafting, concrete printing and D-shape 3Dp are described which, as
11 opposed to the traditional construction method of cutting materials down to size, deliver only what
12 is needed for completion, vastly reducing waste. Also identified is 3Dp's potential to enable buildings
13 to be constructed many times faster and with significantly reduced labour costs. In addition, it is
14 clear that construction 3Dp can allow the further inclusion of Building Information Modelling into
15 the construction process - streamlining and improving the scheduling requirements of a project.
16 However, current 3Dp processes are known to be costly, unsuited to large-scale products and
17 conventional design approaches, and have a very limited range of materials that can be used.
18 Moreover, the only successful examples of construction in action to date have occurred in controlled
19 laboratory environments and, as real world trials have yet to be completed, it is yet to be seen
20 whether it can be it equally proficient in practical situations.

21 *Key Words: 3D Printing; Contour Crafting; Concrete Printing; D-shape; Building Automation.*

22 Introduction

23 The construction industry has traditionally relied on specifications and 2D drawings to convey
24 material properties, performance details and locational information – using small-scale models,
25 typically constructed on wood, to create the object for evaluation as part of the design process.
26 Increasingly, these are being replaced by 3D modelling in the virtual environment of Building
27 Information Modelling (BIM). An alternative is the use of advanced 3D solid modelling techniques in
28 combination with digital fabrication methods (Buswell, 2008). This form of modeling is known as
29 *rapid prototyping*, saving time by the negation of the human modeller, or toolmaker (Buswell, 2007).
30 Rapid prototyping is an automated process referring to techniques that produce shaped parts
31 (models) and is usually done using 3D printing (3Dp) or "additive manufacturing" technology in which
32 successive layers of material are laid down under computer control (Hague and Reeves, 2000). These
33 processes contrast with traditional methods that are either: *subtractive*, starting with a block and
34 machining away material that is not required; or *formative*, shaping or casting material in a mould
35 (Buswell, 2007). In broad terms, components are made by adding, or building up, material to form
36 an object. To do this, the 3D objects are be 'sliced' and represented as a series of 2D layers, with
37 layer based processes sequentially adding each layer to build up the desired object. It is the
38 selectivity and control of the material that enables the freedom to manufacture (or 'build') any

1 desired geometry, which is the fundamental advantage of these processes over more conventional
2 techniques Buswell (2008).

3 In recent times, construction 3Dp has begun to move from an architect's modelling tool to delivering
4 full-scale architectural components and individual elements of buildings such as walls and facades
5 (Lim, 2012). This is further supported by Bassoli, Gatto, Iuliano, & Violante, (2007) who state that
6 “The techniques based on layer-by-layer manufacturing are extending their fields of application,
7 from the building of aesthetic and functional prototypes to the production of tools and moulds for
8 technological prototypes or pre-series”. Specifically, large scale 3Dp such as ‘mega techniques’ is
9 becoming more and more relevant especially since 29 March 2014, when work began on the world’s
10 first 3Dp house (Wainwright, 2014).

11 Little is known, however, of the full role that 3Dp currently plays in the construction industry and
12 where it could be headed in the future. This paper, therefore, provides a literature review in which
13 the advantages and limitations of three selected mega sized 3Dp techniques - contour crafting,
14 concrete printing and d-shape – are described, their current use in construction and potential for
15 future application in the construction industry.

16 **Construction 3Dp**

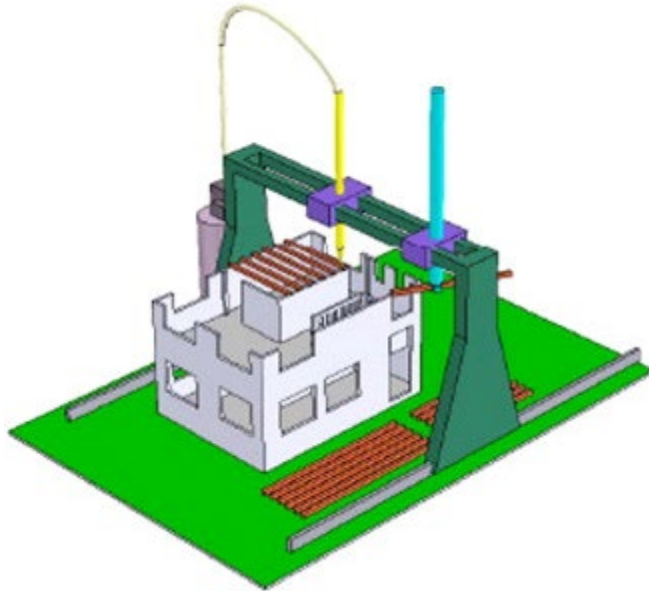
17 According to Lim (2012), there are a number of drivers pushing construction towards automation: a
18 reduction in labour for safety reasons, reducing construction time on site, production costs and an
19 effort to increase architectural freedom. This is supported by Vähä (2013) who adds quality,
20 reliability, life cycle cost savings and the simplification of the workforce as further considerations.
21 There are already numerous examples of automation on construction sites in the form of automated
22 bricklaying, sprayed concrete and precast techniques (Lim, 2012). Construction 3Dp is essentially is
23 just another tool available on the market.

24 **Contour crafting**

25 Contour crafting is a layered fabrication technology that appears to have great potential in the
26 automated construction of whole, small structures that includes some of their subcomponents. It is
27 claimed by the inventor that, by using this process, a single house or even a whole estate of houses
28 may be constructed in a single run while still being possible for each to have a different design
29 (Khoshnevis, 2004).

30 Contour crafting, as a workable building system has been in development for some years. It is based
31 on the practice of emitting multiple layers of a cement-based paste against a trowel, which allows a
32 smooth surface finish to be obtained (Lim, 2012). The application of contour crafting in building
33 construction can be seen in Figure 2, where a gantry system carrying a nozzle moves on two parallel
34 rails that have been installed on the construction site (Khoshnevis, 2004). From here, the computer-
35 controlled gantry runs the same as a small-scale 3D printer, with thick liquid concrete being
36 squeezed out of the nozzle one layer at a time. The lower layers, having been given time to partially
37 cure, are hardened enough to support the weight of the freshly layered cement (Smith, 2012). From
38 here the contour crafting method differs from other 3Dp methods, the key feature being the use of
39 two trowels to create a surface on the object being fabricated that is exceptionally smooth and
40 accurate (Khoshnevis, 2004). Because of the layer-by-layer fabrication method, contour crafting

1 systems have the potential to build utility conduits within walls. This makes the automated
2 construction of plumbing, electrical and structural steel networks within the structure possible
3 (Khoshnevis, 2003). Because of this, it is claimed that contour crafting is able to build a square foot
4 of wall in less than 20 seconds, a whole room in an hour and a 200m² single storey house in a day
5 (Smith, 2012).



6

7 **Figure 1 - Construction of a building using contour crafting on a gantry (Source: Bosscher, Williams & Bryson, 2007)**

8 The automation involved with this method is so complete that the only fixtures that need to be
9 installed by human workers are the door and window pieces that the device is unable to customise
10 (Khoshnevis, 2003). Because of the superior forming capability of the trowels used in contour
11 crafting to create smooth and accurate surfaces, the method it is able to create geometric shapes
12 with almost no limitations of complexity (Smith, 2012).

13 As a result, it is claimed that, due to its speed and ability to use *in-situ* materials contour crafting has
14 potential in two areas: (1) low income housing or emergency sheltered housing; and (2) architectural
15 buildings involving complex shapes that would be expensive to build using traditional methods
16 (Khoshnevis, 2003).

17 **Concrete printing**

18 As with contour crafting, concrete printing is also based on the extrusion of cement mortar in a
19 layer-by-layer process. This print process can be carried out without the use of labour intensive
20 formworks and has the ability to incorporate functional voids into the structure (Lim, Buswell, & Le,
21 2011). However, the process has been developed without the trowels used in contour crafting so
22 that a smaller resolution of depositing is needed to achieve greater levels of 3D freedom. This
23 smaller level of print resolution has, however, resulted in the greater control of internal and external
24 geometries (Lim, 2012).

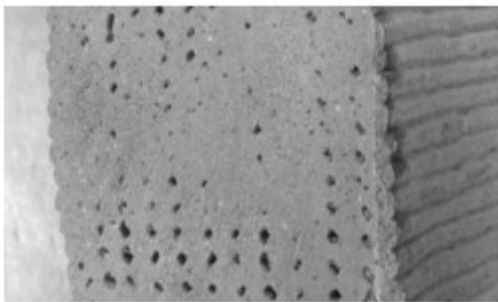
25 Again, compared with contour crafting, the finishing and post processing of concrete printing differ.
26 This is because, due to its nature, concrete printing produces the characteristic ribbed finish seen in
27 Figure 3, which can be controlled and designed to exploit the effect. However, if the desired finish is

1 to be smooth, it requires either trowelling wet material during the building process or subsequently
2 grinding back the printed finish to a smooth surface. This must all be completed by hand because it
3 is not yet feasible to be automated (Lim, 2012).



4
5 **Figure 2 - A concrete printed object: Note the ribbing on the side from the layered approach (Source: Austin, Lim & Le,**
6 **2012)**

7 It should be noted that the layered structure is likely to be anisotropic, as voids can form between
8 the individual filaments of the cement paste as seen in Figure 4, weakening the structural capability
9 (Le & Austin, 2012). Further, Le & Austin (2012) note that the bond between filaments, as well as
10 between layers, influences the hardened properties of concrete components. Therefore, a high
11 strength in compression and flexure as well as tensile bond is the main attribute of this approach.
12 Additionally, a low shrinkage is essential as the freeform components are built without formwork,
13 which could accelerate water evaporation in the concrete and result in cracking (Le & Austin, 2012).
14 Because of these dangers associated with substandard building materials, an in-house high-
15 performance “cementitious” material has been developed with a high strength (around 100~110
16 MPa in compression) - approximately three times that of conventional concrete - in order to
17 compensate for the weaker structure of layered components (Lim, Buswell, & Le, 2011).

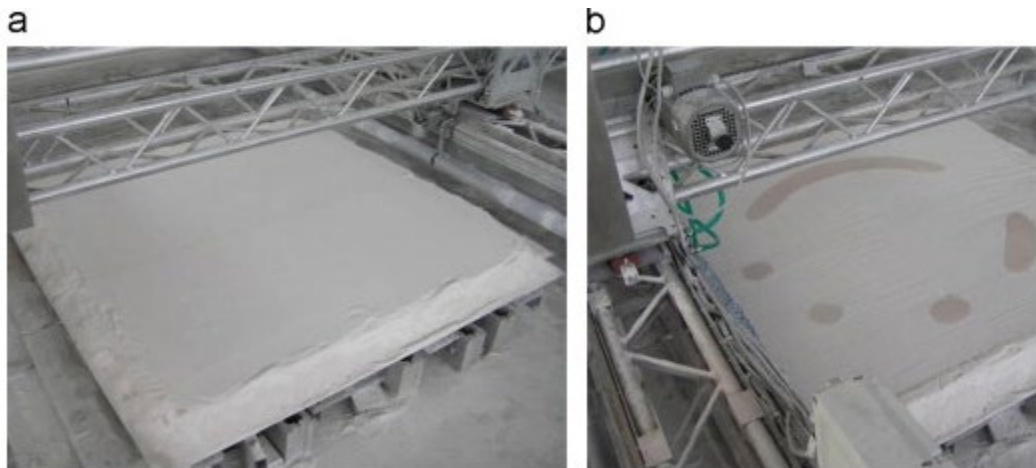


18
19 **Figure 3 - Sectional view of a concrete printed wall: Note the voids formed between the filaments (Source: Le & Austin,**
20 **2012)**

21 **D-shape**

22 The d-shape process uses layers of powder and adhesive rather than the cement-like paste used by
23 the other methods. This involves a powder deposit process, where the ‘powder’ is selectively
24 hardened using a binder, in much the same way as the usual 3Dp process. Each layer of material is
25 laid to the desired thickness, compacted and then the nozzles mounted on a gantry frame deposit

1 the binder where the part is to be solid. Once a part is complete, it is then dug out of the loose
2 powder bed (Lim, 2012) (Figure 5). This automated building system, which uses sand and binder to
3 create stone-like freeform structures, enables full size sandstone buildings to be made without
4 human intervention (Tibaut & Rebolj, 2014).



5
6 **Figure 4 - a. A layer of deposited material ready for adhesive; b. a cross section of the model that has just been printed**
7 **(Source: Cesaretti, Dini, Kestelier, 2014)**

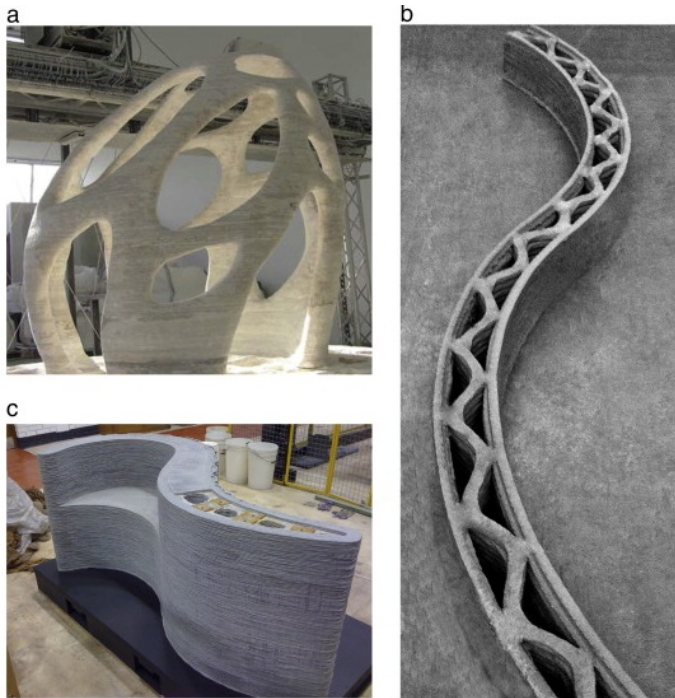
8 The system has many advantages over traditional formative processes (the use of formwork with
9 concrete) as well as other construction 3Dp processes. It is able to use any sand-like material and
10 produces little waste, as the remaining sand that has not adhered to the object can be reused
11 elsewhere. The materials used are all naturally occurring substances that require very little
12 processing before use in the fabrication process. This results in an end product that is very similar to
13 natural stone (Tibaut & Rebolj, 2014).

14 **Comparison of the three techniques**

15 The 3Dp techniques of contour crafting, concrete printing and d-shape are all similar in that they all
16 build additively. However, each of the processes has been developed for different applications and
17 materials, which has resulted in each having distinct individual advantages (Lim, 2012). One of the
18 main differences is whether the head mounting (the part that actually delivers the material to the
19 object) is frame, robot or crane mounted. Contour crafting has been developed to be a crane-
20 mounted device for on-site, *in-situ* applications. Both d-shape and concrete printing are gantry-
21 based off-site manufacturing processes, although with an appropriate amount of modification there
22 is no reason why both processes cannot be used *in-situ* (Lim, 2012).

23 Another major difference between these techniques is the way in which they handle situations
24 where an overhang would exist on the structure. As construction 3Dp relies on building an object
25 from the bottom upwards, overhangs create a particular challenge to these techniques when a
26 section of building requires support. There are two main ways that 3Dp methods handle overhangs.
27 The first is where another material is printed in the void in order to create a very fine section of
28 scaffold that can be broken away later once support is no longer required. The second way is only
29 used by the d-shape system, as it is a powder-based practice. This involves the placement of
30 unconsolidated material, which provides support and is later removed once the drying process has
31 been completed (Lim, 2012).

1 The final important difference in the techniques is the 'print resolution'. This concerns the amount
2 material laid down in each pass of the device. With concrete printing and d-shape placing 4–6mm of
3 material for every pass, as compared with the 13mm that contour crafting inserts - the principle
4 trade off involved being layer depth versus the build speed (Lim, 2012). A smaller amount of
5 material laid results in a longer time taken to reach the desired height, bearing in mind that a smaller
6 amount of material being laid also means a finer control over detail and finish. This can be seen in
7 Figure 1, which provides an example of an object that can be printed by each of these techniques.



8

9 **Figure 5 - An example of the product that each printing process can achieve (a. d-shape; a. contour crafting; c. concrete**
10 **printing.) (Source: Lim, 2012)**

11 **What construction 3Dp techniques can do for the industry**

12 Design uniformity is an essential part of creating affordable and constructible buildings (Buswell,
13 2008). However, clients in recent years have begun requesting more unique and less uniform
14 buildings and concept designs, which are often abandoned because of the extra costs involved. This
15 constraint on original thinking can be overcome by large-scale 3Dp methods that are able to deliver
16 non-repeating components at a cost effective price provided relatively low volumes of production
17 are required. Of this aspect, Pegna (1997) notes that, because the technology offers on-site
18 construction automation, it would be able to reduce the dependence on labour and hence reduce
19 the risk of injuries and weather stoppages. As a result, it is estimated that the technology would be
20 able to reduce construction costs by up to 30% (Pegna, 1997)

21 These techniques are also able to drastically reduce the lead-time to production as well as the cost
22 of design and manufacture of more complex parts that would be difficult or impossible to make with
23 more traditional construction methods (Han & Jafari, 2003).

1 **Waste reduction**

2 The construction industry has long been a leader in waste production. In terms of resource
3 consumption, it is estimated that 40% of all raw materials used globally are used on the construction
4 industry (Lenssen, 1995), with an estimated three and seven tonnes of waste generated by the
5 production of a typical single family home (Khoshnevis, 2003). This is further compounded by the
6 harmful emissions that construction activities generate.

7 Construction machines built for 3Dp may be fully electric and therefore emission free, but one of the
8 main savings is from the need for less people resulting in less vehicles being driven to and from the
9 construction site, saving large amounts of fuel (Smith, 2012). In addition, the accurate nature of
10 additive fabrication enables 3Dp techniques that result in little to no material waste (Khoshnevis,
11 2003). This reduction in waste is brought about in a number of ways, chief among which is the saving
12 of formwork and mould making. In buildings, almost every wall, panel and partition is uniquely
13 dimensioned, which means that, for construction to be cost effective, either standard size materials
14 are cut to fit or custom moulds are made to form each part. Construction 3Dp allows the printer to
15 obviate these approaches and just produce what will actually be needed for the final structure -
16 freeing designers to create what they want and where they want without the need for economies of
17 scale to keep the cost down (Lim, 2012).

18 Furthermore, large-scale printing allows the integration of mechanical and electrical services within
19 the structure, resulting in reduced amounts of wasteful and time-consuming builder's work (Buswell,
20 2007). This, in essence, allows the building to be considered as a homogenous unit, negating the
21 need for difficult interface detailing, reducing the chance of error and hence costly remedial work
22 (Buswell, 2007).

23 **Further incorporation of computer modelling**

24 As Lim (2012) notes, the development of Building Information Modelling (BIM) will undoubtedly
25 increase the use of digital information and will likely drive the application of automated modelling
26 and manufacturing processes in construction. This is further supported by Vähä (2013), who
27 comments that the automation of building production requires the exploitation of information
28 models in each phase of the working process, i.e., the use of BIM throughout the construction
29 lifecycle. In addition, Vähä (2013) outlines the four types of data acquisition needs required by an
30 automated construction process: 1) positioning, 2) tracking, 3) progress monitoring and 4) quality
31 control.

32 BIM is often used to visualise sensor readings in construction and facilities management for the
33 location and tracking of resources (Vähä, 2013). This heavy incorporation of computer modelling
34 that construction automation brings, is both necessary and advantageous to the industry. Buswell
35 (2007) observes that the coupling of digitally controlled processes with solid modelling techniques
36 will mean greater design freedom at no extra cost. These savings can be found in places such as
37 complex cores and cavities in an object, which can be produced directly from a CAD model, complete
38 with all necessary systems and avoid the construction of patterns and core boxes that would
39 otherwise be necessary (Bassoli, Gatto, Iuliano, & Violante, 2007).

40 This enforced digitalisation that automation brings can help in rectifying of the problems that
41 already exist in the industry and specifically where 3Dp is concerned. As stated by Bak (2003), when

1 discussing 3Dp, “the great advantages, in terms of relatively low costs and very low times for casting
2 availability, contrast with the very poor knowledge concerning the limits of application and the
3 process performances.”

4 **Implications on labour**

5 There is a growing skills shortage in the construction industry, which will be further compounded in
6 the future by the aging population in the UK, Australia and many other countries (Buswell, 2007).
7 With the additional problem of safety still a major issue -the construction industry being one of the
8 most hazardous environments encountered - it is clear that action is needed. Mega-sized 3Dp is able
9 to reduce the amount of personnel required on site at any one time. This is because machines such
10 as those used in contour crafting are lightweight and can be quickly assembled, disassembled and
11 transported by a small crew. In addition, the construction operation can be fully automated so that
12 only minimum supervision is required (Zhang, 2013).

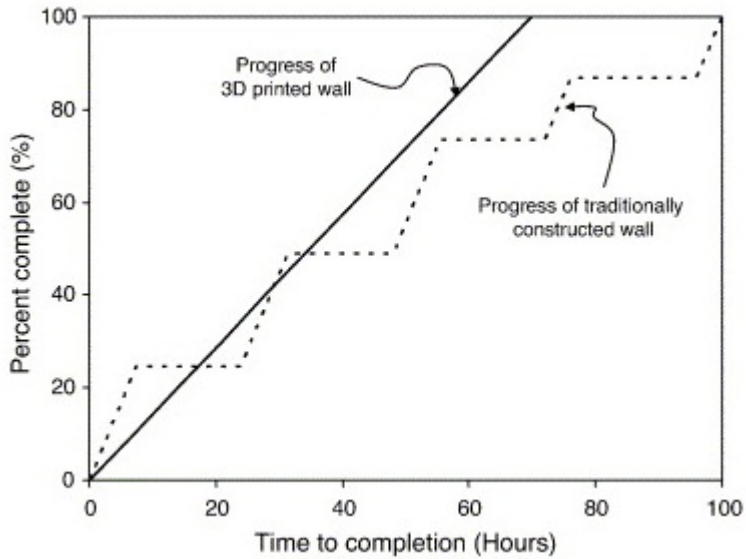
13 When used on small residential buildings, the full-scale machine splits into three pieces in order to
14 fit onto a small flatbed truck, minimising the labour required in transportation and logistics. Again
15 using contour crafting as an example, with the vast majority of the construction on site being
16 automated, humans play a supporting role. They lay out supplies for the robotic arm and prepare
17 fresh batches of concrete, as well as complete tasks such as installing windows and doors that are
18 not worth automating or too hard to automate (Smith, 2012).

19 **Speed**

20 The creator of the contour crafting method claims great increases in building speed for those
21 utilising his method. He states that estimates show that the contour crafting method will be capable
22 of completing the construction of an entire house in a matter of few hours (e.g., less than two days
23 for a 200 m² two storey building) instead of several months. This increase in speed of the building
24 process directly results in an increase in efficiency of logistics and management (Khoshnevis, 2003).

25 The increase in speed can be attributed to construction 3Dp methods always operating at a steady
26 and unrelenting pace, unlike more traditional methods that include breaks for workers or concrete
27 curing. An example of this increase in speed can be seen in Figure 6, first proposed by Buswell (2007)
28 who describes the production of a typical wall section found in a domestic home. The wall is
29 assumed to be 5 m long and 3 m high and is to be made up of a 13 mm of internal plaster finish on
30 100 mm concrete blocks, with a 50 mm cavity and 100 mm external facing bricks. Fixings, brick ties,
31 insulation, etc., are not included in the example. The Figure compares the more traditional building
32 method (dotted line) and the 3Dp process (solid line).

33 The steps in the traditional methods come from having to leave every ~ 1 m height in brickwork
34 overnight for the mortar to cure (the maximum weight allowed on wet mortar). Accepting that there
35 is no operational efficiency in the labour allocation (continuous work) and neglecting the set-up time
36 for the machine, 3Dp is comparable in building time to traditional methods because it can work at a
37 constant rate with every layer it places being supported by the layers underneath.



1

2 **Figure 6 - A time graph showing the time taken to complete both a traditional and 3Dp wall (Source: Buswell, 2007)**

3 **Limitations of construction 3Dp**

4 Since the early years of the 20th century, automation has grown and prospered in almost all
 5 production domains other than the construction industry. The adoption of automation into the
 6 industry has been slow due to multiple factors, chief among which are (Khoshnevis, 2004; Hwang &
 7 Khoshnevis, 2004; Vinodh, Sundararaj, Devadasan, Kuttalingam, & Rajanayagam, 2009):

- 8 • unsuitability of the available automated fabrication technologies for large scale products,
- 9 • conventional design approaches that are not suitable for automation,
- 10 • a significantly smaller ratio of the quantity of final products as compared with other industries,
- 11 • limitations in the materials that could be employed by an automated system,
- 12 • economic unattractiveness of expensive automated equipment and
- 13 • managerial issues

14 Moreover, buildings are unlike many other products in that they cannot be easily mass-produced
 15 (Hodson, 2013). Each building is a prototype of its own, built on different sites, with different
 16 conditions, and different materials for different clients. All of this results in a product that is hard to
 17 standardise or make amenable to computerization (Hodson, 2013). Despite their differences, all
 18 three designers of the 3Dp processes believe passionately that 3Dp will eventually make a radical
 19 contribution to construction. However, they acknowledge, too, that the technology is so 'disruptive'
 20 that the cautious and conservative nature industry will inevitably make its diffusion a slow process,
 21 at least initially (Smith, 2012).

22 **Appropriateness for large scale/mass development**

23 Construction components of significant size are heavy, typically being up to 5 tonnes. This makes
 24 lifting and moving parts an endeavour to be avoided where possible. This means that the *in-situ*
 25 deposit approach, printing parts on site followed by assembly or ultimately printing large parts of a
 26 building or other infrastructure *in-situ*, would be a good option for production of a structure. The
 27 disadvantage of construction 3Dp *in-situ*, however, is the sensitivity of the materials and processes

1 to ambient conditions that could interfere with on-site applications (Lim, 2012). In addition,
2 materials in all three techniques harden through a curing process, with the contour crafting and
3 concrete printing processes both being wet processes, while d-shape is mainly a dry process. This
4 results in a curing process that is inherently less controllable than the heat or UV based methods of
5 conventional building (Lim, 2012). Moreover, several physical constraints need to be considered
6 during the entire construction process whilst printing, comprising (Zhang, 2013):

- 7 1. The nozzle idle time cannot be too long, otherwise concrete may solidify and block the
8 machine.
- 9 2. The lower layer must be able to support the upper layer, therefore the time interval
10 between depositing subsequent layers cannot be shorter than the minimum curing time.
- 11 3. Subsequent layers must be able to adhere, therefore the interval between depositing
12 subsequent layers should not exceed a critical limit.
- 13 4. The printing nozzles cannot be allowed to collide with the previously deposited layer or
14 other nozzles when traveling. Because of this, when moving between the end points of wall
15 segments, the nozzle may not be able to travel in a straight line in order to avoid obstacles.

16 These factors, together with the limitations of strength of the materials that can be used in 3Dp,
17 suggest that conventional building methods are likely to continue to be used for multistorey,
18 heavyweight buildings involving straightforward building processes, and that 3Dp would be best for
19 lightweight structures that are “funky but expensive”. Only later, once the technology has grown and
20 the features have become cheaper, is its use envisaged for more mainstream projects (Khoshnevis in
21 Smith, 2012).

22 **Current cost of the technology**

23 One of the main problems facing large-scale construction 3Dp is that, although automation has
24 advanced in manufacturing, its growth in the construction industry has been slow. This is because
25 the conventional methods used in automated manufacturing do not lend themselves to the
26 construction of large structures with internal features (Khoshnevis, 2004). This inflexibility can be
27 attributed to several factors, but the fundamental problem is that design approaches in construction
28 are not suitable for automation. Any object that is to be produced by an automated system must
29 first be wholly designed and outlined on a program able to fit with the system capabilities as well as
30 an additional assembly sequence having been written for the object (Khoshnevis & Hwang, 2006). All
31 of this comes at an additional cost and relies on advanced planning.

32 Additionally, construction 3Dp has a smaller production quantity compared with other methods. It
33 can only be used as a solution when identical or similar products are mass-produced (Khoshnevis
34 & Hwang, 2006). In addition, there is a severe limit in material choices when using 3Dp processes
35 (Khoshnevis, 2004). This is because there only only certain materials that can pass through these
36 machines and still be able to be used in a way they are intended without either destroying the
37 machine or deforming the object that is being constructed.

38 Perhaps of most significance is that these techniques are accompanied by high initial equipment
39 costs as well as significant ongoing maintenance costs (Khoshnevis & Hwang, 2006). This type of
40 automation requires significant start-up fees and specially (and expensively) trained operators. In
41 addition, every new site involving a printer would have different individual needs that must be

1 programmed into the machine for them to be taken into account – resulting in additional costs and
2 time. Moreover, the automated systems that would operate in the outside world on dirty worksites
3 would need frequent downtime for cleaning and maintenance.

4 Finally, an additional obstacle to the implementation of the technology is the need for support
5 systems. As Smith (2012) comments “What’s the point in having a technology which can build a
6 house in a day when the US building inspectors come out 10-12 times to check things over and it
7 take weeks to schedule all the appointments?”.

8 **Conclusion**

9 With clients asking designers for structures that cannot be built by any known method today, new
10 processes such as 3Dp techniques are a likely solution. In addition to this, with factors such as the
11 need to reduce production costs and time on site, additional safety concerns, a push to increase
12 architectural freedom, raising standards of quality and a wish to simplify the work to counter the
13 lack of skilled workers, the construction industry is gradually edging closer to automation. This is
14 particularly the case with construction 3Dp techniques and their advantages such as the ability to
15 produce nonstandard buildings/nonrepeating sections at a reasonable cost, that was virtually
16 impossible previously. Just the ability to go straight from a computer program to the manufacture of
17 a structure reduces the lead-time by such a degree that major cost savings are made in this alone.
18 Adding savings of up to 30% in waste, makes construction 3Dp a very attractive proposition indeed.

19 On the other hand, the technology has some severe limitations for use in construction work. The
20 current unsuitability for automated processes for truly large scale fabrication, the severely limited
21 scope of the materials that are currently able to be used in construction, the high price that would
22 have to be paid by the pioneers of the industry in simple things such as training, organisation and
23 management, together with the price of the equipment itself is quite prohibitive. Furthermore, the
24 support of local building associations must first be established if such relatively simple matters as
25 building inspections are to be completed in a sufficiently timely and competent manor.

26 For construction 3Dp methods to be successful in the future there must be an ability for all the
27 processes involved to be able to be performed on site with little to no effect of the everyday
28 outdoor conditions of building sites. An additional issue is that with equipment involving robotic
29 workers, the technology should be easy to use and have intuitive user interfaces and be able to
30 share work spaces with workers as well as encompass a high level of safety (Vähä, 2013). Without
31 such functionality, it seems likely to present day observers that automated construction 3Dp will not
32 be in widespread use for many years to come.

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