

# Additive Manufacturing Technology in Orthodontic Devices Development

W.F.Tang, S.L.Mak, C.H.Li



**Abstract:** Traditional wires and brackets has been widely used as orthodontic devices for long time. The metal wires and brackets help to correct the position of teeth as well as fix the cavity. However, metal brace wires have quite a lot limitations. Patients wearing metal brace have many food restrictions and feel not comfortable. Brushing and flossing are required to remove the food debris frequently. Hence, clear plastic aligners have popped up recently. Since the metal brace fabrication process has associated with prolonged process time as a result of a long workflow process starting from brace mold presentation to the prosthesis execution. The growing of additive manufacturing technology make it possible to develop complex structures and shapes of dental brace. By combining 3D oral scanning, it is possible to shorten the lead time of orthodontic treatment process. This review, therefore, investigates the use of Digital Light Processing (DLP) Additive Manufacturing Technology for plastic dental brace development as a remedy to the problems associated with the traditional methods. The study reveals that it is feasible to fabricate these plastic braces utilising the DLP technology. DLP technology is affordable and arguably able to produce dental models with high levels of assurance and accuracy.

**Keywords :** dental brace, clear aligners, orthodontic device, additive manufacturing, stereolithography, fused deposition modelling

## I. INTRODUCTION

Dental braces are pieces of equipment that are used to strengthen and align teeth. These divides leverage force or pressure to help improve a person's bite or the dental health and hygiene; they can be used to correct underbites, overbites, malocclusions, deep bites, crooked teeth, crossbites, open bites, and various other flows on the jaw and the teeth (Sorooshian and Kamarozaman 2018). According to Benson et al. (2015), braces can either be structural or cosmetics and are used in combination with other orthodontic appliances to aid in widening the jaws, the palate, and otherwise help in dental shaping. There are essential components that traditionally constitute braces including the ligature elastic

(O-ring), bonding material, brackets, and the teeth, however, occasionally rubber bands or spring can be applied to put more force in a given direction (Wang et al., 2016).

Millett et al. (2017) add that braces apply constant pressure which loosens the tooth and allows for the growth of a new bone to support the tooth in its new position, a process referred to as bone re-modelling, and with time moves the teeth into the desired positions. According to Kaluderović, Schreckenbach and Graf (2016), bone deposition also forms a critical factor in the movement of the tooth that happens at the distracted periodontal ligament in order to prevent loosening and occurrence of voids distal to the direction of tooth movement. Some common types of braces include traditional metal wires, gold plate stainless steel, lingual braces, titanium braces, progressive, clear removable aligners, and the customised orthodontic treatment systems (Alkadhimi 2020).

## II. PROBLEM STATEMENT

Even with their universal application, the current studies show several concerns with these metal-based braces as a method of orthodontic correction. First, the process is associated with a more prolonged process time as a result of a long workflow process starting from brace mold presentation to the prosthesis execution. The traditional metal-braces molding methods are associated with accuracy limitations in the final output, causing uneasiness or discomfort among patients after installation (Uno et al., 2019). Further, studies demonstrate that multiple adjustments can extend treatment and reverie time (Kiviat and Fleming 2018). Fourth, using metal braces has a negative social outcome due to the perception of "a mouth full of metal" (Uno et al., 2019). Also, metal braces are associated with diet and food restrictions because sticky or hard foods can dislodge or break the metal wires from the teeth leading to prolonged treatment time as a result of multiple distortions of braces or breakages (Kiviat and Fleming 2018). Lastly, another primary concern is the cleaning of teeth. Lastly, it is quite difficult to brush and floss teeth when metal braces are deployed (Alkadhimi, 2020)

This review, therefore, investigates the use of Digital Light Processing (DLP) Additive Manufacturing Technology for plastic dental brace development as a remedy to the problems associated with the traditional methods. According to Javaid and Haleem (2019), additive manufacturing is growing to make it possible to develop complex structures and shapes, including the dental field, because the fabrication of plastic teeth braces requires complex and precise structures. Therefore, by combining digital scanning and 3D printing, it is possible to design custom clear plastics braces as a replacement of the traditional metal braces for orthodontic correction within short lead time.

Revised Manuscript Received on August 12, 2020.

\* Correspondence Author

W.F.Tang\*, School of Science and Technology, The Open University of Hong Kong. Email: fwftang@ouhk.edu.hk

S.L.Mak, School of Science and Technology, The Open University of Hong Kong. Email: lunmak@ieec.org

C.H.Li, School of Science and Technology, The Open University of Hong Kong. Email: chli@ieec.org

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

The primary aim of the review is to assess the current state of dental brace development by using Digital Light Processing (DLP) additive manufacturing technology and the feasibility of using these technologies in creating plastic braces to replace the traditional metal braces and their associated problems.

In this regard, the following constitute the primary study objectives,

1. To investigate the current 3D printing and scanning methods
2. To explore the 3D printing of Digital light processing (DLP) technology.
3. To evaluate the current state of fabrication of clear plastic braces for orthodontic corrections.

### Research Questions

The following constitute the primary research questions;

- a) How applicable is Additive Manufacturing in Orthodontics?
- b) In what ways can clear plastic braces solve the issues associated with metal for orthodontic corrections?
- c) What is the feasibility of applying DLP additive manufacturing technology in the fabrication of clear plastic braces?

### III. BRACE TECHNOLOGY DEVELOPMENT

#### • Metal-based Wired Braces

The traditional metal-based wired braces are the most commonly studied and applied methods (Millett et al. 2017). According to Kiviat and Fleming (2018), metallic braces entail a stainless-steel that sometimes is combined with titanium. The braces have a metal bracket with elastic rubber band ties straining the wire onto the metal brackets; however, self-ligating braces type do not require elastic ties because the wire goes through the bracket. The second category is associated with shorter treatment time, less pain on the teeth, and fewer adjustment -requirement than the first type. The gold-plated stainless steel is deployed upon patients who are nickel-allergic; however, some chose them for the aesthetic value of gold. The use of titanium is similar to steel braces but achieves the same objective with a lighter material. A novel strategy is the use of progressive, clear removable aligners. This method is used for non-complex orthodontic cases, including palate expansion, extractions, or jaw surgery to move teeth to their final position (Javaid and Haleem 2019).

#### • Plastic (Invisalign) Braces

Invisalign is a clear set of hard plastic aligners fitted for the mouth to help correct crowded or crooked teeth. These items must undergo checking and placing during an initial couple of months to align the teeth correctly in their positions. The choice of braces is popular; clear aligners are practically invisible (Szuhanek et al. 2017). Unlike the metallic braces, these plastic braces provide more comfort when worn (Bowman 2017). These braces are devoid of wires or brackets, therefore, are not associated with painful cuts and nicks in the mouth. Further, Shivapuja et al. (2019) posit that the plastic braces do not irritate the mouth as a result of being smooth and lack sharp edges (Comba et al. 2017). Because the plastic aligners are clear, the feeling and perception of a mouth full of metal do not exist. In the research by Szuhanek, Fleser and Grigore (2015), participants thought that the

plastic braces were more attractive to the eye and in many cases go unnoticed by many people. As such, a user of plastic braces can feel free to smile without the need to be overly self-conscious. Further, the cost of clear aligners is comparatively lower compared to the metal based-braces due to material and technology used. Szuhanek et al. (2017) observe that prices of braces have an insignificant dependence on the treatment plan, extent and duration of the issue requiring correction, location, time and age of the treatment or the orthodontist's experience. In a related study by Shivapuja et al. (2019), the researcher observes that since the plastic aligners have become available on a widespread scale in straightening teeth, they are perceived convenient and healthy; therefore, no one may require to deal with metal braces any more. The fact that these braces can be removed when eating, flossing, or brushing teeth, unlike metallic braces. Therefore, a user is able to practice effective oral hygiene and reduces the risk of suffering from gum disease and can also eat the food of choice (Gomez et al. 2015). Bowman (2017) adds that unlike traditional braces, the plastic braces ensure that a user does not worry about food particles getting stuck. Most importantly, plastic braces are easy to maintain. According to Vandenberghe (2018), the braces can get dingy with time, but cleaning freshens them up. The process of cleaning can be done using a toothbrush dipped in a small amount of bleach and water (Szuhanek, Fleser and Grigore 2015). In contrast, Weir (2017) argues that the plastic braces are associated with several adverse outcomes, first, they are expensive to purchase, second, the attachments that go along with the plastic braces make them more noticeable, are expensive, and are required to be worn at least 22 hours of the day (Jindal et al. 2019). Additionally, plastic braces are also associated with tooth discomfort and inconvenience. Participants of the study by Comba et al. (2017) reported using pain relievers before their teeth adjust to the plastic braces. The user is also required to remove them every time during meals and in order to clean the teeth..

### IV. ADDITIVE MANUFACTURING PROCESSES DEVELOPMENT

The primary processes involved in the 3D printing process include the acquisition of data, data processing, additive fabrication, and post-processing procedures. According to Francois et al. (2017), the data acquisition sequence can be achieved by leveraging the contact or non-contact scanning devices. The original equipment includes cone beam computerised tomography (CBCT), computerised tomography (CT), laser digitising (intraoral or extraoral scanning devices) and magnetic resonance imaging (MRI) (Gokuldoss, Kolla and Eckert, 2017). The sequence then shifts to data processing that involves the use of specific computer-aided design (CAD) software to create a virtual design of the object (Harun et al. 2018).



Upon the design completion, the STL file generated is imported on the printer software which controls the process of slicing and addition of support structures based on the parameters and the build variable information it generates to control the operation on the 3D printer (Ziemian, Sharma and Ziemian 2012). The next phase of the sequence, additive fabrication is responsible for building the object utilising a Slice file in the 3D printer.

Lastly, during the post-processing phase post-curing to help complete the polymerisation process and the cleaning of the object is undertaken. However, the post-processing procedures are printer or technology-specific, and therefore depends on the recommendations of the manufacturer (Francois et al. 2017).

- *Digital Light Processing (DLP)*

The DLP additive manufacturing technology is considered similar to SLA (Mu et al. 2017), with a primary difference in the source of light. In the DLP, image creation is by the digital mirror device (DMD); this is a microscopic mirror in a matrix within the semiconductor chip or an arch lamp (Thrasher, Schwartz and Boydston 2017). According to Zuzak et al. (2013), each microscopic mirror represents a unit or multiple pixels in the projected images; thus, the number of mirrors is directly proportional to projected image resolution (Nayar and Boulton 2014). A projector under safelight conditions projects light to a vat composed of liquid polymer, and the projector displays the image of the desired object onto the liquid polymer. In the DLP additive manufacturing technology, the desired object is pulled out from the liquified resin and not down, further into the liquid photographic system. The radiation passes the rug; the ultraviolet transparent window, the process is then repeated until the desired object is fully built (Mu et al. 2017).

In a study to assess the performance of DLP AM technology in terms of effectiveness and adequate accuracy for clinical applications under a variety of orientations as well as settings, the researchers collected oral impressions from 15 patients to make 3-dimensional printed models (Sherman et al., 2020). The researchers tested for the following variable of the printing method; hollow vs solid shell, placement on the build plate (corner vs build), and thickness in the z-axis (50 vs 100) microns. The researcher then printed the impressions using the different orientations and printing techniques on the same printer; the researcher then measured a total of 240 mandibular and maxillary arches. The printer yielded a total of eight combinations of print. The researcher then measured and compared the arch and tooth from individual models. Further, the researcher used the intraclass correlation coefficient to assess the intra observer reliability of the repeated measurement error (Sherman et al., 2020).

Sherman et al. (2020) established highly reproducible results as a result of the high intraclass correlation coefficient for all the record measures. All the mean differences retrieved from the protected combinations were statistically significant. Further, there was an observably high degree of agreement among all the sets of models and printing variations as verified by the Bland-Altman plots. As such, the experiment proved that the DLP printer produced clinically acceptable models in all build-plate areas with solid and hollow model

shells and at its high-speed setting of 100 microns. Therefore, the DLP AM printer should be a viable option for orthodontics within a clinical environment at a high-speed mode; however, the build plate should be filled with less resin while filling the build plate. Similar results are replicated in the study by Oliveira (2019), the study showed better trueness value for DLP, the researcher however obtained a discrepancy ranging between 20-50 $\mu$ m, which is insignificant for a clinical trial.

In a related study by Jasiul et al. (2018) to compare the accuracy of dental models printed by the DLP compared to other technologies including SLA and UDP technologies, twelve 3D digital surface models were selected, exported as stereolithographic surface models and then printed at 50 $\mu$ m and 100 $\mu$ m. The researchers then created a digital STL file out of the scans and then superimposed to the original scan. The research study outcome revealed no statistical significance in the difference in the layer of thickness between DLP, SLA and UDP. As such, these technologies could be utilised to obtain a desired level of accuracy. However, Lee et al. (2017) in their study also observed that the DLP AM technology is not valid when printing multiple models simultaneously, spread out entirely around the build platform to produce results of desired quality because the technology has the tendency of object quality degradation when spread towards the edge of the build platform.

- *Stereolithography (SLA)*

The SLA is an additive manufacturing process that primarily constitutes the following steps; first, the SLA building platform is submerged in a liquified resin polymerised by ultraviolet laser (Partolo 2011). Second, a pre-programmed design of the object is drawn using UV laser for layer formation; because the photopolymer is UV-light sensitive, the photochemical solidification of the resin occurs to form a unit layer of the desired 3D object. Third, upon complete polymerisation of the layer, the process of descending the building platform is initiated; the platform descends at a distance equivalent to the thickness of the layer allowing for coverage of the previous layer by incurred resin (Choi et al. 2011). This process is repeated several times until the building of the printed object is complete. According to Melchels, Feijen and Grijpma (2010), the completed parts require washing using UV light to clean wet resin from the surface. The SLA utilises laser technology to trace out the object cross-section. A set of lenses is used to focus the laser, which is then reflected off the galvanometer, which constitutes double motorised scanning mirrors. Melchels, Feijen and Grijpma (2010) posit that the z-axis resolution is determined by the depth of cure controlled by the irradiant exposure conditions and the photoinitiator, including velocity, wavelength, and power, pigments, dyes, or added UV absorbers. The layer thickness of the SLA process, in general, is dependent on the standard of the printer model, which ranges between 5-150  $\mu$ m having a surface roughness of about (35-40)  $\mu$ m Ra. Further, the UV light wavelength useful during the material polymerisation depends on the printer. It ranges between (200-500) nm.

## Additive Manufacturing Technology in Orthodontic Devices Development

According to Partolo (2011), SLA technology is associated with the freedom of printing complex geometries besides being temperature resistant. The ability of the SLA technology to allow for bottom-to-up printing makes it possible to ensure that the build volume is significantly more prominent than the vat and that only a sufficient photopolymer is utilised to sustain the bottom of the build with a continuous supply of photopolymer (Kiviat and Fleming 2018).

However, the success of the process is significantly dependent on the support structures which consume additional material leading to extended post-processing and production time (Melchels, Feijen and Grijpma 2010). The supporting structures attach to the elevator platform and help resist lateral pressure from the resin-filled blade, mitigate the deflection due to gravity, and retain the freshly created sections during bottom-to-up printing. The supports are automatically created during CAD models preparations; however, they can also be manually generated, but are removed mechanically upon completion of the printing process (Partolo 2011).

### • Polyjet Printing (PP)

This process involves the selective jetting of liquid resin out of hundreds of nozzles and the polymerisation with ultraviolet light (Sood, Ohdar and Mahapatra 2010). According to Choi et al. (2011), the curing using the UV is done upon a desire for the virtual design, and because the process utilises multiple print nozzles, the co-deposition of supporting material occurs. Singh (2011) posits that the distinct variations in colour or building materials possessing a variety of properties can be designated, including structures having spatially graded properties (Castiaux et al. 2019).

### • Fused Deposition Modelling (FDM)

This is an additive manufacturing technology based on the thermoplastic material extrusion. In this approach, the material is drawn via a nozzle, heated, and deposited in layers (Anitha, Arunachalam and Radhakrishnan 2001). The nozzle movement is horizontal, but the platform movement is vertically downward or upward. According to Sood, Ohdar and Mahapatra (2010), the final model quality depends on several factors; however, the technology shows excellent potential upon successful control of the factors. While this technology demonstrates more significant similarity with other AM methods, it is unique because of material added in a continuous stream and under constant pressure. Ziemian, Sharma and Ziemian (2012) posit that this pressure must be kept steady for an accurate outcome. Chemical agents or temperature control strategies can be deployed to bond material layers.



**Figure 1. Dental mold produced by Fused Deposition Modelling method**

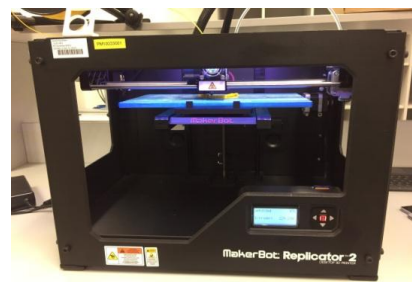
Making a perfect square nozzle is currently impossible; therefore, the nozzle responsible for material deposition is designed with a radius impacting on the quality of the

outcome of the printed object (Anitha, Arunachalam and Radhakrishnan 2001). According to Dul, Fambri and Pegoretti (2016), the quality of the final model depends entirely on the nozzle's material thickness. The speed and accuracy are also considerably low compared to other processes. Based on the study by Singamneni et al. (2010), it is critical to consider the tension and gravity in the event the process is being used for components where achieving high tolerance is a primary requirement (Sood, Ohdar and Mahapatra 2010). In this technology the layer thickness ranges from (0.178-0.356) mm

### • The current 3D Printing Equipment for Orthodontics

The field of orthodontics is currently benefiting from a more efficient and cost-effective workflow utilising state-of-the-art technology due to the evolution of the 3D imaging and modelling industry. Several dental fields demonstrate the practicability of 3D imaging and modelling techniques, including oral maxillofacial surgery and prosthesis, prosthodontics, physical models, and or surgical guides in dental implant treatment. According to Vandenberghe (2018), orthodontic appliances can be fabricated using three-dimension printed models as a result of the workflow shift to a digital format. Therefore, these technologies are more affordable and are able to produce dental models with high levels of assurance, precision, and accuracy. Recent advances in 3D scanning technologies have led to the invention of intraoral scanners that help eliminate unpleasant impressions while ensuring reduced treatment time and accuracy of appliances for patients setting the ground for the development of 3D printing to work in conjunction with scanners.

Moser, Santander and Quast (2018) posit that every 3D print equipment requires a separate computer workstation to initiate any printing task. Some printers, however, are integrated with the workstation itself; the printer also requires a build tray for model fabrication, and a print medium including, sand, plastic, metal, human cells, clay which is in many cases printer-specific. Some of the commonly used 3D printers include objet30 OrthoDesk, Ultra 3SP Ortho, MakerBot and other FDM printers.



**Figure 2. Markerbot 3D printer**

## V. RESULTS AND DISCUSSIONS

### • Applicability of DPL Additive Manufacturing

The study has established that in order to make the process of manufacturing plastic aligners sustainable, the braces have to be considerably cheaper compared to the metal braces.



Therefore it is necessary to establish a cost model by identifying the key components that contribute to the cost per part of the equipment, develop a mathematical relationship associating the parameters of the process and also the need to allocate the overhead costs (Jiang 2019; Partolo 2011). The study also shows that with the cost model in place, it is possible to quickly adopt the DLP for the fabrication of plastic aligners (Castiaux e al. 2019; Dawood et al. 2015 ). Further, cost modelling is suggested to have a positive come on the advancement of AM advancement.

The study has also established the capability of DLP technology to print different features with various aspect ratios and sizes. The study, however, points out that this possibility is dependent on exposure time, geometry, film thickness, and printing layer thickness (Davoudnejad et al. 2017; Castiaux e al. 2019).

The study has also shown the possibility of improving the AM technology in terms of material consumption, building time, and surface quality. The study shows that by adopting segmentation designs, it is possible to reduce material consumption by reducing the support structures (Hilliard 2008; Uno et al. 2019). Building time can also be reducing segment height. These aspects help reduce surface roughness. In terms of DLP performance, the current study shows that the DLP printed is faster. They can print builds with multipart that take much part of the build platform. The study also demonstrates that it is also faster in printing large, fully dense prints. The study suggests a part of ideas in order to improve the precision and accuracy of DLP AD, for instance, ensuring the right temperature for the nozzle, treating the filament with care and the application of different builds with respect to the different effects (Davoudnejad et al. 2017; Kiviat and Fleming 2018).

The study has also demonstrated that the integration of digital solutions has revolutionised treatment planning and diagnosis from traditional approaches like 2D to the current 3D roaches, which have been rapidly integrated into orthodontics. The AD processes including facial and intraoral scanners, cone-beam computed tomography, digital radiology and additive manufacturing processes can, therefore, be used to create an equipped office for orthodontic reality (Dawood et al. 2015; Kiviat and Fleming 2018). Unlike the traditional computer-aided design and computer-aided manufacturing, 3D technology allows for the capture of high-resolution 3D virtual models. With 3D technology, it is possible to leverage the non-contact optical technologies and principles without causing discomfort to the patient, or any other negative outcome regarding lab work or imprecision (Marotti et al. 2013; Kazemi and Rahimi 2019).

#### • Effectiveness Plastic Aligners

Plastic aligned are made out of flexible plastic. Using plastic aligners is observed by the study outcome as widespread (Gomez et al. 2015; Vandenberghe 2018). The widespread acceptance of plastic aligners is attributed to their transparent colour. Therefore the users can use the plastic brakes without the worry of the negative social outcome (Hilliard 2008; Szuhaneck et al. 2017; Alkadhimi, 2020). The study also shows that these braces are relatively cheaper to produce compared to metallic aligners (Charalambis et al. 2017; Comba et al. 2017). The relatively affordable prices make them ideal for use in orthodontics. Further, the study results show that plastic aligners do not irritate the mouth and

are associated with convenience. The user can remove the braces when eating, cleaning the teeth, unlike the metallic braces. Another aspect that is widely discussed by the reviewed sources is the aspect of the easy maintenance associated with the plastic braces. The researcher suggests the use of a toothbrush dipped in a small amount of bleach and water (Kazemi and Rahimi 2019; Haleem 2019). However, care should be taken to follow the orthodontist's directions appropriately to prevent adverse health outcomes.

## VI. CONCLUSION AND RECOMMENDATION

The purpose of this review was to establish the current state of AM technology application in orthodontics and the possibility of applying this technology to fabricate plastic braces leveraging the DLP AM technology. The review has revealed that AM technology has become of age and is already being applied in dentistry. The review also shows that the manufacture and use of plastic braces is happening widely and with significant acceptance mainly due to considerably low prices, clearer look, the convenience of use and the comfort associated with their use. These pieces of equipment can, therefore, be used to replace the traditional metal braces that are perceived by users to be lacking discomfort and the perception of having "a mouth full of metal."

The study also reveals that it is feasible to fabricate these plastic braces utilising the DLP technology, the reviewed studies demonstrate that the DLP technology is affordable and arguably able to produce dental models with high levels of assurance, precision, and accuracy within a short period. However, the associated processes and requirements have to be fulfilled. Further, the fact that the plastic braces are widely accepted, it is possible to produce them in mass due to the availability of the market. As a result of the more reasonable price of the DLP printers, the availability of software to help align and produce sequential models based on the teeth movement, and the acceptance of the clear plastic braces, the project is not only viable by feasible. Since companies are developing resins that allow for the direct printing of clear aligners makes the whole process more cost-effective and efficient. As a recommendation, this study proposes that current manufacturers of transparent plastic braces should ensure to minimise the cost of production to keep the product price low and the demand high, proper marketing should also be encouraged for the products and to encourage investment as only a few companies can manufacture plastic braces. Future research should also be undertaken to investigate the best way to counter the social concerns associated with the use of clear plastic braces.

## ACKNOWLEDGMENT

The work described in this paper was fully/substantially/partially supported by the Open University of Hong Kong Research Grant (No. 2019/1.12).



## REFERENCES

- Alkadhimi, A., 2020. Safe braces. *British Dental Journal*, 228(10), pp.739-739.
- Bártolo, P.J. ed., 2011. *Stereolithography: materials, processes and applications*. Springer Science & Business Media.
- Benson, P.E., Da'as, T., Johal, A., Mandall, N.A., Williams, A.C., Baker, SR and Marshman, Z., 2015. Relationships between dental appearance, self-esteem, socio-economic status, and oral health-related quality of life in U.K schoolchildren: A 3-year cohort study. *European journal of orthodontics*, 37(5), pp.481-490.
- Bowman, S.J., 2017, March. Improving the predictability of clear aligners. In *Seminars in orthodontics* (Vol. 23, No. 1, pp. 65-75). WB Saunders.
- Castiaux, A.D., Pinger, C.W., Hayter, E.A., Bunn, M.E., Martin, R.S. and Spence, D.M., 2019. PolyJet 3D-printed enclosed microfluidic channels without photocurable supports. *Analytical Chemistry*, 91(10), pp.6910-6917.
- Charalambis, A., Davoudinejad, A., Tosello, G. and Pedersen, D.B., 2017. Cost estimation of a specially designed direct light processing (DLP) additive manufacturing machine for precision printing. In *euspen's 17th International Conference & Exhibition*. The European Society for Precision Engineering and Nanotechnology.
- Choi, J.W., Kim, H.C. and Wicker, R., 2011. Multi-material stereolithography. *Journal of Materials Processing Technology*, 211(3), pp.318-328.
- Comba, B., Parrini, SIMONE, Rossini, G.A.B.R.I.E.L.E., Castrolorio, T. and Deregibus, A., 2017. Three-dimensional finite element analysis of upper-canine destabilisation with clear aligners, composite attachments, and class II elastics. *J Clin Orthod*, 51(1), pp.24-8.
- Davoudnejad, A., Pedersen, D.B. and Tosello, G., 2017. Characterization of additive manufacturing processes for polymer micro parts productions using direct light processing (DLP) method. In the 33rd *International Conference of the Polymer Processing Society (PPS-33)*.
- Dawood, A., Marti, B.M., Sauret-Jackson, V. and Darwood, A., 2015. 3D printing in dentistry. *British dental journal*, 219(11), pp.521-529.
- Dul, S., Fambri, L. and Pegoretti, A., 2016. Fused deposition modelling with ABS-graphene nanocomposites. *Composites Part A: Applied Science and Manufacturing*, 85, pp.181-191.
- Francois, M.M., Sun, A., King, W.E., Henson, N.J., Tourret, D., Bronkhorst, C.A., Carlson, N.N., Newman, C.K., Haut, T.S., Bakosi, J. and Gibbs, J.W., 2017. Modelling of additive manufacturing processes for metals: Challenges and opportunities. *Current Opinion in Solid State and Materials Science*, 21(LA-UR-16-24513; SAND-2017-6832J).
- Garino, F., Castrolorio, T., Daher, S., Ravera, S., Rossini, G., Cugliari, G. and Deregibus, A., 2016. Effectiveness of composite attachments in controlling upper-molar movement with aligners. *J Clin Orthod*, 50(6), pp.341-7.
- Gomez, J.P., Peña, F.M., Martínez, V., Giraldo, D.C. and Cardona, C.I., 2015. Initial force systems during bodily tooth movement with plastic aligners and composite attachments: A three-dimensional finite element analysis. *The Angle Orthodontist*, 85(3), pp.454-460.
- Gokuldoss, P.K., Kolla, S. and Eckert, J., 2017. Additive manufacturing processes: Selective laser melting, electron beam melting and binder jetting—Selection guidelines. *Materials*, 10(6), p.672.
- Harun, W.S.W., Kamariah, MSIN, Muhamad, N., Ghani, S.A.C., Ahmad, F. and Mohamed, Z., 2018. A review of powder additive manufacturing processes for metallic biomaterials. *Powder Technology*, 327, pp.128-151
- Hilliard, J.K., 2008. *System and method for fabricating orthodontic aligners*. U.S. Patent Application 11/842,411.
- Javaid, M. and Haleem, A., 2019. Current applications and status of additive manufacturing in dentistry: A literature-based review. *Journal of craniofacial and oral biology research*, 9(3), pp.179-185.
- Jasiuk, I., Abueidda, D.W., Kozuch, C., Pang, S., Su, F.Y. and McKittrick, J., 2018. An overview of additive manufacturing of polymers. *Jom*, 70(3), pp.275-283.
- Jesson, J., Matheson, L. and Lacey, F.M., 2011. *Doing your literature review: Traditional and systematic techniques*. Sage.
- Jindal, P., Juneja, M., Bajaj, D., Siena, F.L. and Breedon, P., 2020. Effects of post-curing conditions on mechanical properties of 3D printed clear dental aligners. *Rapid Prototyping Journal*.
- Jiang, J., 2019. Support Optimisation for Additive Manufacturing.
- Kaluderović, M.R., Schreckenbach, J.P. and Graf, H.L., 2016. Titanium dental implant surfaces obtained by anodic spark deposition—from the past to the future. *Materials Science and Engineering: C*, 69, pp.1429-1441.
- Kazemi, M. and Rahimi, A., 2019. Improving the efficiency of fabrication of AM parts by segmentation design in the DLP process. *Rapid Prototyping Journal*.
- Kiviat, J. and Fleming, Y., 2018. Orthodontic Appliance Intolerance Due to Dental Adhesive Allergy. *Dermatitis*, 29(6), pp.349-350.
- Lee, H., Lim, C.H.J., Low, M.J., Tham, N., Murukeshan, V.M. and Kim, Y.J., 2017. Lasers in additive manufacturing: A review. *International Journal of Precision Engineering and Manufacturing-Green Technology*, 4(3), pp.307-322.
- Marotti, J., Heger, S., Tinschert, J., Tortamano, P., Chuembou, F., Radermacher, K. and Wolfart, S., 2013. Recent advances of ultrasound imaging in dentistry—a review of the literature. *Oral surgery, oral medicine, oral pathology and oral radiology*, 115(6), pp.819-832.
- Melchels, F.P., Feijen, J. and Grijpma, D.W., 2010. A review on stereolithography and its applications in biomedical engineering. *Biomaterials*, 31(24), pp.6121-6130.
- Millett, D.T., Mandall, N.A., Mattick, R.C., Hickman, J. and Glenny, A.M., 2017. Adhesives for bonded molar tubes during fixed brace treatment. *Cochrane Database of Systematic Reviews*, (2).
- Moser, N., Santander, P. and Quast, A., 2018. From 3D imaging to 3D printing in the dentistry—a practical guide. *International journal of computerised dentistry*, 21(4), pp.345-356.
- Mu, Q., Wang, L., Dunn, C.K., Kuang, X., Duan, F., Zhang, Z., Qi, HJ and Wang, T., 2017. Digital light processing 3D printing of complex conductive structures. *Additive Manufacturing*, 18, pp.74-83.
- Nayar, S.K. and Boulton, T.E., Columbia University of New York, 2014. *Adaptive imaging using digital light processing*. US Patent 8,675,119.
- Oliveira, G., 2019. Accuracy And Precision Of 3-dimensional Printed Dental Models Produced By Different Additive Manufacturing Technologies.
- Resnik, D.B., 2015. What is ethics in research & why is it essential—*National Institute of Environmental health sciences?*
- Sherman, S.L., Kadioglu, O., Currier, G.F., Kierl, J.P. and Li, J., 2020. Accuracy of digital light processing printing of 3-dimensional dental models. *American Journal of Orthodontics and Dentofacial Orthopedics*, 157(3), pp.422-428.
- Shivapuja, P.K., Shah, D., Shah, N. and Shah, S., Real 3d Polymers Group LLC, 2019. *Direct 3D-printed orthodontic aligners with torque, rotation, and full control anchors*. U.S. Patent 10,179,035.
- Shkarin, V.V., Davydov, B.N., Domyenyuk, D.A. and Dmitrienko, S.V., 2018. Non-removable arch orthodontic appliances for treating children with congenital maxillofacial pathologies—efficiency evaluation. *Archiv EuroMedica*, 8(1), pp.97-98.
- Singh, R., 2011. Process capability study of polyjet printing for plastic components. *Journal of mechanical science and technology*, 25(4), pp.1011-1015.
- Singamneni, S., Diegel, O., Huang, B., Gibson, I. and Chowdhury, R., 2010. Curved-layer fused deposition modelling. *Journal for New Generation Sciences*, 8(2), pp.95-107.
- Sood, A.K., Ohdar, R.K. and Mahapatra, SS, 2010. Parametric appraisal of mechanical property of fused deposition modelling processed parts. *Materials & Design*, 31(1), pp.287-295.
- Szuhanek, C., Grigore, A., Schiller, E., Bratu, D.C., Onisei, D. and Onisei, D., 2015. The role of digital setup in the orthodontic treatment with plastic aligners. *Mat. Plast*, 52, p.522.
- Szuhanek, C., Fleser, T. and Grigore, A., 2015. Applications of Thermoplastic Materials in the Fabrication of Orthodontic Aligners. *Mat. Plast*, 52, p.385.
- Sorooshian, S. and Kamarozaman, A.A., 2018. Fashion braces: an alarming trend. *Sao Paulo Medical Journal*, 136(5), pp.497-498.
- Thrasher, C.J., Schwartz, J.J. and Boydston, A.J., 2017. Modular elastomer photo resins for digital light processing additive manufacturing. *ACS applied materials & interfaces*, 9(45), pp.39708-39716.
- Uno, M., Yokokawa, Y., Kawaki, H., Oka, T., Tamaki, Y. and Ishigami, H., 2019. Investigating the effectiveness of ceramic materials, particularly zirconium oxide, and the advantages the white metal holds over traditional materials used in dentistry: impact, 2019(2), pp.68-70.
- Vandenbergh, B., 2018. The digital patient—Imaging science in dentistry. *Journal of dentistry*, 74, pp.S21-S26.

47. Wang, X., Gao, W.Y., Luan, J., Wojtas, L. and Ma, S., 2016. A most effective strategy to boost the robustness of metal-organic frameworks via the introduction of size-matching ligand braces. *Chemical Communications*, 52(9), pp.1971-1974.
48. Weir, T., 2017. Clear aligners in orthodontic treatment. *Australian dental journal*, 62, pp.58-62.
49. Ziemian, C., Sharma, M. and Ziemian, S., 2012. Anisotropic mechanical properties of ABS parts fabricated by fused deposition modelling. *Mechanical engineering*, 23.
50. Zuzak, K.J., Cadeddu, J.A., Uffret-vincenty, R., Francis, R.P. and Livingston, E., University of Texas System, 2013. *Digital light processing hyperspectral imaging apparatus*. US Patent Application 13/776,105.

### AUTHORS PROFILE



**Ir Dr. Fanny Tang**, Wai-fan is currently the Senior Lecturer in Testing and Certification, School of Science and Technology, the Open University of Hong Kong. She is also the Director of Recognition of Prior Learning (RPL) Assessment Agency for Testing, Inspection and Certification (TIC). She obtained her Doctor of Education

from the Nottingham Trent University (UK), Master of Engineering (Hons) in Industrial Engineering Management from the University of Hong Kong and Bachelor of Science (Hons) in Applied Physics from the City University of Hong Kong. Prior to joining the OUHK, she worked as consultant in Hong Kong Productivity Council and has extensive experience in industrial engineering management, material testing, reliability testing and failure analysis. She is appointed as the member of Hong Kong Council for Testing and Certification by the Innovation and Technology Commission. She is also appointed as Technical Assessor by the Hong Kong Accreditation Service (HKAS) and the fellow of the Hong Kong Institution for Certified Auditors (HKICA). Her research interests include material failure analysis, reliability engineering and higher education curriculum development. Her research interests include, Material Science and Properties, Reliability Engineering, Failure Analysis and Higher Education Curriculum Development. The latest publications are listed as follows.

- Fanny Tang, S. L. Mak and C. H. Li (2019), 'Strategic Approach for the Implementation of New ISO/IEC 17025:2017 Quality Management Systems: A Review on Risk Management and Data Management'. The Proceedings of the 2019 International Conference on Systematic Innovation, ISI, July, 2019 Liverpool, UK
- Fanny Tang (2018), 'Content Analysis Approach: A Review on the Extent of Science and Engineering Curriculum Meet Competency Requirements for Testing, Inspection and Certification Industry', Proceedings of 2018 Conference on Industrial Engineering and Engineering Management (IEEM2018), Thailand.
- Fanny Tang (2018), 'A Review on the Self-Cleaning Glass Technology Applied in Automobile', Proceedings of the 2018 IEEE International Symposium on Product Compliance Engineering (ISPCE), China \*Received "Merit Award" in the paper competition.
- Fanny Tang and Eddy Chan (2018), 'Systematic Identification for Workforce and Competency Requirements for Testing, Inspection and Certification Sectors', Proceedings of the 2018 International Conference on Systematic Innovation (ICSI), Taiwan
- Fanny Tang (2017), 'Content Analysis Methodology: A Review on the Readiness on Science and Engineering Curriculum in Higher Education Institution in Supporting Undergraduates to Enter the Testing and Certification Industry', Proceedings of the 2017 IEEE International Symposium on Product Compliance Engineering (ISPCE), Taiwan
- Fanny Tang, Anne O'Grady and Andrew Clapham (2017), 'Entering the Testing and Certification Industry: A Review of Job and Competency Requirements', Proceedings of 2017 Conference on Industrial Engineering and Engineering Management (IEEM2017), Singapore.
- Fanny Tang, (2017) 'Innovative-driven Strategies for Growth Industries: A Review on Engaging Testing and Certification Industry', Proceedings of the International Conference on Systematic Innovation (ICSI), Beijing, China. \*Received "Excellent Presentation Award" in the paper presentation

Her membership in professional institutions are listed as follows:

- Technical Assessor of The Hong Kong Laboratory Accreditation Scheme (HOKLAS) of the HKSAR Government
- Member of the Hong Kong Institution of Engineers
- Member of Hong Kong Council for Testing and Certification (HKCTC)

- Fellow of the Hong Kong Institution for Certified Auditors (HKICA)
- Low Carbon Manufacturing Programme Verifier (LCMP) of World Wide Fund (WWF)
- Certified Factory Auditor of Hong Kong Exporters' Association



**Ir Dr. SL Mak**, is Assistant Professor in the School of Science and Technology. He received his M.Sc in Automation System & Management, B.Eng(Hons) in Manufacturing Engineering from City University of Hong Kong, Master of Electronic Commerce (MEC) and Doctor of Engineering (D.Eng) from The Open University of Hong Kong. He is the Chartered Engineer in United Kingdom, Fellow of Institution of Mechanical Engineers (UK), Fellow of the Institute of Measurement and Control (UK), Member of the Institution of Engineering and Technology (UK), Registered Professional Engineer and Certified Testing Professional (Toys and Children Products, Hardlines) in Hong Kong. Ir Dr. Mak had worked in the testing and certification industry for 20 years before he joined the Open University of Hong Kong. The research areas include, Control, Automation and Instrumentation, Product Safety Testing and Engineering Design, Quality Engineering and Management, Innovation Technology Adoption. The publications are listed as follows:

- P. K Sum and S. L. Mak, 'Alcohol sensitive car starting system', The HKIE CAD 2018/19 Paper Context, HKIE, 2019, ISBN 9-789627-619741
- C H Li and S. L. Mak, 'An implementation of Industry 4.0 Assessment Model in Product Safety', The HKIE CAD 2018/19 Paper Context, HKIE, 2019, ISBN 9-789627-619741
- Y.T. Tung, W.K. Ko, S.M. Mok, W. H. Chiu, S. L. Mak, W. F. Tang, C.H. Li and D.M. Ke, 'A Critical Review on Safety of Slime Toys', The HKIE CAD 2018/19 Paper Context, HKIE, 2019, ISBN 9-789627-619741
- C. W Kwong, S. L. Mak, C. H. Li, 'A Critical Review on China Toy Factories Dealing with US and European Toy Safety Requirements', The HKIE CAD 2018/19 Paper Context, HKIE, 2019, ISBN 9-789627-619741
- Fanny Tang, S. L. Mak, Jimmy Li. A Review of Science and Engineering Curriculum Design for Testing, Inspection and Certification Industry. Higher Education Research, 2019 ISSN: 2578-9341 (Print); ISSN: 2578-935X (Online)
- S. L. Mak, C. H. Li, W. F. Tang, C. W. Lai. Design and Verification of Acoustic Room for Consumer Product Safety Testing. Engineering and Applied Sciences. Vol. 5, No. 3, 2020, pp. 50-55. doi: 10.11648/j.eas.20200503.11
- S. L. Mak, C. H. Li, Fanny W. F. Tang, 'A Critical Review on the Adoption of Information Technology in Modern Manufacturing Operation'. 2020 Annual Journal of HKIE CAD, HKIE, 2020, ISBN 9-789627-619741
- C.H. Li, S. L. Mak, L.Y. Kwok, H.Y. Yuen, T.K. Lee, Fanny Tang, 'Evaluating the integration of Blockchain Technology in Testing, Inspection and Certification Industry (TIC)'. 2020 Annual Journal of HKIE CAD, HKIE, 2020, ISBN 9-789627-619741
- S. L. Mak, Fanny W. F. Tang, C. H. Li, and Geddy T W, Lee, 'The Influence and Good Practice of Product Recall on Brand Image and Customer Perceived Product Quality', International Journal of Business, Humanities and Technology (IJBHT) Vol. 7 No. 2., 2020 ISSN 2162-1357(Print); ISSN 2162-1381 (Online); DOI: 10.30845/ijbht.v10n2p2

His membership in professional institutions are listed as follows:

- Vice Chairman and Treasurer, The Institute of Measurement and Control, Hong Kong Section
- Chairman (2016-2017) and Hon Secretary (2018-), The IEEE – Product Safety Engineering Society, Hong Kong Chapter
- Panel Member (2017-) - Food and Health Bureau (FHB) - Fishermen Claims Appeal Board (Trawl Ban)
- Panel Member (2017-2020) - Home Affairs Bureau (HAB) – Appeal Board Panel of the Amusement Rides (Safety) Ordinance
- Youth Development Coordinator (2017-2020), The Institution of Engineering and Technology, Hong Kong
- Panel Member (2015-2018), Electrical and Mechanical



# Additive Manufacturing Technology in Orthodontic Devices Development

Service Department - Appeal Board Panel under the Builders' Lifts and Tower Working Platforms (Safety) Ordinance, Cap 470

- Scheme A External Engineering Supervisor (2014-) and Professional Interviewer (2015-), The Hong Kong Institution of Engineers
- Committee member (2014-), The Hong Kong Institution of Engineers – Control, Automation and Instrumentation Division
- Committee member (2013-), The Hong Kong Institution of Engineers – Manufacturing and Industrial Division
- Technical Assessor - Hong Kong Accreditation Service (HKAS)



**Ir Dr. Li Chi Ho Jimmy**, is currently the Senior Lecturer in the School of Science and Technology. He obtained his Bachelor of Engineering from City University of Hong Kong, Master of Engineering from Hong Kong Polytechnic University,

Master of Business Administration from City University of Hong Kong and Doctor of Engineering from The Open University of Hong Kong.

Ir Dr. Li is a Chartered Engineer in Hong Kong and United Kingdom, he is active in the academic and professional communities. Currently, he is the International Professional Registration Advisor and Assessor of different engineering professional associations (e.g. IET, IMechE, InstMC); Registered Auditor in Hong Kong and Mainland China; and Vice Chairman of Manufacturing and Industrial Engineering Section (MIES) of the Institution of Engineering and Technology (IET), Hong Kong.

Before joining OUHK, he worked in Hong Kong Productivity Council and responsible for implementing quality management consultancy projects as well as developing training programmes. He has extensive experience in improving operation process, reengineering business structure and analysing product failure through diagnosis and consultancy programmes. The research areas include, Industry 4.0, MiC Construction, DFMA Process Design and Control, Technology and Innovation Management. The publications are listed as follows:

- S. L. Mak, Fanny Tang and C. H. Li., "The Influence and Good Practice of Product Recall on Brand Image and Customer Perceived Product Quality", Vol. 10 No. 2, International Journal of Business, Humanities and Technology.
- Fanny Tang, S. L. Mak, C. H. Li. A Review of Science and Engineering Curriculum Design for Testing, Inspection and Certification Industry. Higher Education Research, 2019 ISSN: 2578-9341 (Print); ISSN: 2578-935X (Online)
- C. Y. Ngan, Y. C. Yu, H. T. Chung, Z. T. Yeung and C. H. Li, 'A Study of Wearable Robotic Exoskeleton Arm (IoARM) for Testing and Certification Industry', The Proceedings of the HKIE CAD 2018/19 Paper Context, HKIE, 2019, ISBN 9-789627-619741
- Y. T. Tung, W. K. Ko, S. M. Mok, W. H. Chiu, S. L. Mak, W. F. Tang, C. H. Li and D. M. Ke, 'A Critical Review on Safety of Slime Toys', The Proceedings of the HKIE CAD 2018/19 Paper Context, HKIE, 2019, ISBN 9-789627-619741
- C. H. Li and S. L. Mak, 'An Implementation of Industry 4.0 Assessment Model in Product Safety', The Proceedings of the HKIE CAD 2018/19 Paper Context, HKIE, 2019, ISBN 9-789627-619741
- C. W. Kwong, S. L. Mak, C. H. Li, 'A Critical Review on China Toy Factories Dealing with US and European Toy Safety Requirements', The Proceedings of the HKIE CAD 2018/19 Paper Context, HKIE, 2019, ISBN 9-789627-619741
- C. H. Li and S. L. Mak, 'An implementation of Industry 4.0 Assessment Model in Product Safety', The Proceedings of the HKIE CAD 2018/19 Paper Context, HKIE, 2019, ISBN 9-789627-619741

His membership in professional institutions are listed as follows:

- International Professional Registration Advisor (IPRA) of The Institution of Engineering and Technology (IET)
- Monitored Professional Development Scheme (MPDS) Mentor of Institution Of Mechanical Engineers (IMechE)
- International Professional Review Interviewer (PRI) of The Institution of Engineering and Technology (IET)
- International Professional Review Interviewer (PRI) of Institution Of Mechanical Engineers (IMechE)
- Professional Review Assessor of The Institute of Measurement and Control (MInstMC)

- Vice Chairman, Product and Safety Engineering Society (Hong Kong Chapter) of The Institute of Electrical and Electronics Engineers (IEEE)
- Senior Qualification Manager, The Institute of Measurement and Control (MInstMC) (Hong Kong Section)
- Vice Chairman, Manufacturing and Industrial Engineering Section of The Institution of Engineering and Technology (IET) Hong Kong
- Honorary Treasurer, Manufacturing and Industrial Engineering Division of The Hong Kong Institution of Engineers (HKIE)
- Vice Chairman, Youth Service Committee, Rotary Club of New Territories, Rotary International 3450 District