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# CURRENT AND FUTURE OPPORTUNITIES FOR 3D PRINTING IN MODERN BOARD GAMES

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## Abstract

Additive manufacturing (3D printing) is a set of disruptive technologies where parts are no longer produced by removing material until the desired form is achieved, but rather build the intended product layer by layer. With significant benefits in the efficient use of resources, optimizing performance, and allowing individual customization of each print, 3D printing techniques have been more widely adopted worldwide, and modern board games are no exception. However, until now its use is mostly hobbyists creating and sharing 3D models for improving player experience in two aspects: customization (upgrade) of game components, and solutions for organization/setup/logistics. Nevertheless, 3D printing opens opportunities also for game designers/developers and publishers. This paper presents a glimpse of the current use of 3D printing in modern board games and discusses opportunities for the future, highlighting how both players and professionals can take advantage of this technology.

**Keywords:** 3D printing; additive manufacturing; board games; tabletop games; player experience

## Introduction

Additive manufacturing, more commonly referred to as 3D printing, are technologies that create parts by additive means rather than (traditional) subtractive processes (Gibson, 2014, ASTM, 2021). That means that material is deposited by layers only in the amount needed to produce the part (eventually in addition to support structures), and with significant geometric freedom, unlike subtractive processes such as CNC machining (e.g. milling and turning). As an example, the automotive industry has embraced additive manufacturing in recent years for producing custom parts, tooling, and even for entire vehicle structures given the advantages offered by this technology (Berman, 2021). The additive manufacturing industry grew by 7.5 percent to nearly $12.8 billion in 2020, despite the ongoing global Covid-19 pandemic, having grown on average 27.4% over the previous decade (Wohlers, 2021). The economic implications of additive manufacturing, which also apply to how they will affect the tabletop games industry, were discussed by several authors (Christian, 2015, Frederic, 2015).

There are several advantages to additive manufacturing compared to traditional manufacturing methods; first, it allows producing complex geometries with intricate internal structures which otherwise would be difficult (or even impossible) to achieve using traditional techniques. The possibility of 3D printing to create customized components and produce them on-demand, and locally, has boosted its global adoption for both serious and entertainment purposes (Berman, 2021).

The additive manufacturing process (Gibson, 2014) is usually comprised of the following stages: 1) creation of a 3D digital model by using dedicated computer graphics software, such computer-aided design (CAD) or 3D modelling software; 2) preparing the model for the printer, through a digital process called 'slicing', using specific software to transform the 3D model into thin cross-sectional layers which are to be deposited sequentially by the printer; 3) building the object by layers in the 3D printer; 4) finishing and post-processing, including cleaning the model, removing supports, curing in the specific case of printing with resins, and eventually painting the model as desired.

If we consider the additive manufacturing technologies available on the market at the time of this work, the most commonly used are fused deposition modeling (FDM), stereolithography (SLA), and selective laser sintering (SLS). These technologies allow working with various materials, mostly polymers or metals, but also ceramics, composites, and biomaterials, in different degrees of detail, complexity, size, and cost. It is this wide range of possibilities that creates a lot of application space for 3D printing.

It is already common knowledge that 3D printing had a significant impact on several industrial sectors, and modern board games are no exception. The technology offers both game designers and players new possibilities for prototyping, customization, and overall enhancement of the gaming experience. In a wider perspective, this can be said of the entire toy industry (Sheng, 2022). In fact, a study by Chen (2017) highlights how 3D printing enables the customization of toys. Akin to the type of customization and personalization that can also be valued in modern board games, this study explores the application of 3D printing to customize toys to meet individual preferences,

thus emphasizing possible service-oriented production approaches. Service-oriented manufacturing (Sun, 2008, Luo, 2014) is highly relevant to understand possible paths forward for 3D printing in the context of modern board games.

There are two main trends in the use of 3D printing in modern board games over the last few years: design and customization of games (by players / the community), and prototyping and testing (by designers / companies).

Using standard domestic 3D printers, players can produce their own designs and customize game components at will, although some knowledge is required both from the point of view of using the hardware as from that of modifying/creating models with specialized software (which even though is continuously becoming more accessible, is still a barrier to many potential users). The potential of 3D printing in fostering more personalized game experiences through the local production of custom tokens, miniatures, and other components has been highlighted by several researchers (Bhaduri, 2017, Petersen, 2017). It can also play an important role and have substantial impact in player engagement and community interaction, as players can interact in both local groups and global communities to create and share 3D-printed components, enabling creative exchange of ideas and options. Such interactions can strengthen local gaming communities and contribute to improve the gaming experience (Bhaduri, 2017).

The logistics of printing should also be mentioned. Although several online services are available to order 3D prints from STL models, most of these are international and the shipping costs for domestic uses can be forbidding. In many countries/regions, local 3D printing is starting to be widely available either at public libraries or other municipal facilities. However, one of the most promising approaches are *fabLabs*, which are small workshops dedicated to digital fabrication (not only 3D printing) to the public, based on the 'maker' culture and allowing anyone to produce prototypes through several technologies (Soomro, 2022). Very often *fabLabs* are associated with high schools or universities, but also industrial parks and incubators. International stores that provide printing on demand are starting to explore the possibility of offering 3D printing services, and in the future this might be common.

On the other hand, game designers and game developers can take advantage of 3D printing to prototype and iterate their designs, contributing to increase the quality of the final product (Petersen, 2017). Early play testing can benefit from having slightly more realistic parts, but even more significant is the possibility of rapid iteration of shapes, sizes, and options for components, something that until recently was unthinkable. Designers can thus assess both the feasibility and functionality of a design as well as being able to make more informed decisions about the level of detail and geometric features of the game components in a timely manner, before committing to mass production (Petersen, 2017).

There are, however, several very important aspects to be considered. First, the quality and durability of most 3D printed parts produced by hobbyists (the majority of which is obtained by FDM), at the time of this work, is not comparable to injection molded parts, nor is the range of available materials (Bochnia, 2021). However, as 3D printing technology is still evolving and many efforts are currently underway aiming to

improve the quality and durability of 3D printed parts, materials and techniques used in 3D printing (in particular FDM) are advancing, for example through innovative functionalized monofilaments for the toy industry (León-Cabezas, 2017). Second, there are several copyright and intellectual property rights issues (Bradshaw, 2010), and it is important to realize the limits imposed by legislation, in particular when creating and distributing 3D-printable files for game components (Seaman, 2022). Third, while 3D printing has tremendous opportunities in terms of customization and prototyping, its use in board game production runs is considerably more limited in terms of production scale and associated costs (Petersen, 2017). Compared to traditional manufacturing technologies for large series, the cost of 3D printed parts are significantly higher per part, and even with printer farms, the production volumes are nowhere near what injection molding can achieve.

The use of 3D printing in board games (and entertainment purposes as a whole), leads also to an issue recently growing in importance: sustainability. Both filament and resin 3D printed parts represent more plastic parts that need to be treated at their end-of-life. Additionally, these techniques lead to some waste from the manufacturing process. While it is not a significant amount of new material in use (in particular since most gamers will hold to their 3D prints indefinitely or as close as possible to that), parts should be produced in a responsible manner. Luckily, current technology allows properly repurposing and recycling the resulting plastic waste, as discussed by Nur-A-Tomal (2020) in a sustainability case-study of transforming waste from children's toys into high-quality products.

Finally, another application of 3D printing in a related area should be mentioned, namely to create pedagogic material in secondary education. Kostakis et al (Kostakis, 2015) used 3D printing in high schools, with the involvement of students collaboratively designing and manufacturing artifacts, to enable constructionist learning. They found such approaches can foster creativity and inclusion, plus promoting student engagement, through the materialization of ideas. Such mindset is akin to the use of 3D printing in modern board games.

## Current uses of 3D printing in board games

For years, 3D printing has been mostly employed in board games by enthusiasts/fans. There are several cases of kickstarter campaigns where pieces are 3D printed, but the majority of use cases are geometric 3D models created and made available in online platforms that hobbyists print in order to improve or customize their favorite games. Many such models are freely available. This paper is focused on the hobbyist perspective of 3D printing in modern board games.

The main purposes of 3D models available for board games include (but are not limited to):

- Organization and storage (box inserts, tile trays, card boxes, etc),
- Game logistics support (holders, health counters, dice towers, player boards, etc),
- Improved realism of components (geometrically representative parts rather than simple cylindrical or brick shapes, textured terrain tiles, custom dice, etc),
- 3D versions of market standard 2D game pieces (essentially "miniatures" rather than "standees" versions, which

is mostly distinctive for game characters, walls, buildings, effect markers, etc),
- Community-created board games (some games were designed from scratch to be 3D printed at home),
- Customization and theme-gating (such as chess pieces mimicking a set of known characters).

However, in order to analyze exactly how widespread 3D printing is within the modern board games community, we can look at the largest database of information related to board games, namely the BGG (board games geek) web portal (https://boardgamegeek.com). In that portal, there are community-made "geeklists" (these are user-created lists of selected BGG entries, often used to enumerate a particular subset of games), which represent a compendium of information about specific topics within the portal. The two geeklists most relevant to the present discussion are "3D prints for board games" (Robert Johansson, n.d.) and "Super-best-ultimate list of free (non-insert) 3D prints for games" (Ben Vaterlaus, n.d.). The former includes all types of components created to enhance the experience of playing board games, while the latter excludes inserts (which is the largest use case).

As shown in Figure 1, for the 2 major groups of models made available by the community (found under 2 specific geeklists), the general number of models that are focused on upgrades but excluding inserts is circa 377. That is approximately 12.5% of the total number of 3D models available (circa 3013), highlighting how the majority of models concern organization and storage (namely, inserts).

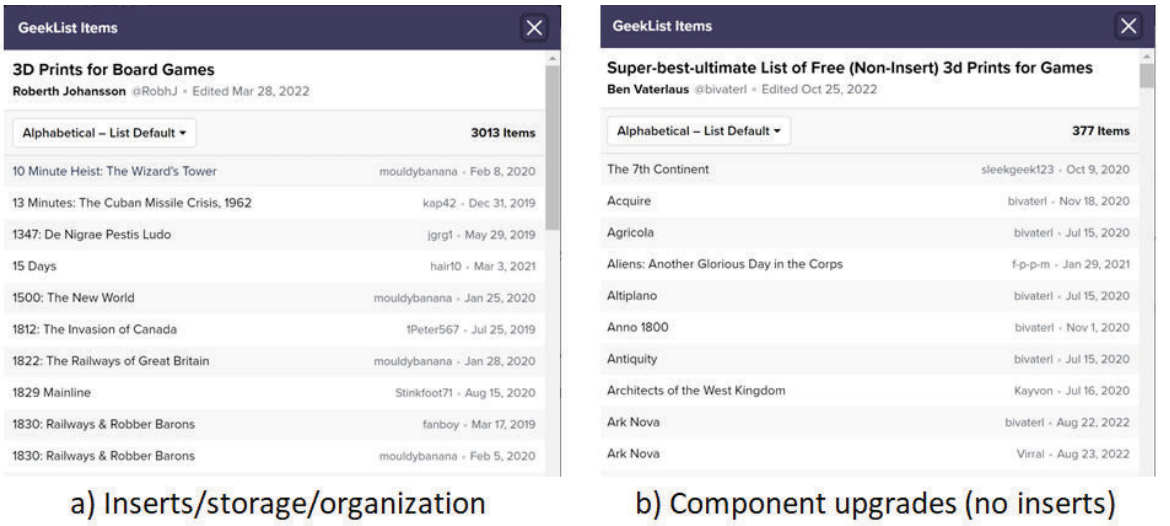


Figure 1
(a) 3D components for board games including inserts, and (b) components for board games excluding inserts.

Another important aspect is how long ago such models started being shared by the community. Although it is difficult to pinpoint the first shared models, even because some of the platforms where older models were shared might no longer be available, and some posts in online board that had 3D models have since been discontinued, we can identify the onset of major interest by the time when the aforementioned geeklists were created. As shown in Figure 2a, the more generic geeklist was created on February 2015, already compiling a series number of models that were scattered throughout different publications on the portal (18 entries were created on the day of the geeklist creation date). In Figure 2b, we can see the more specialized geeklist without inserts was created on July 2020 (with 47 entries on the creation date), catering to players who are looking to enhance gaming experience aside from simply storing and organizing the game components. In that figure we can also observe which were the first games for which components were inserted in those geeklists.

One of the most interesting aspects to analyze is identifying which games have attracted the most effort by gamers to create 3D models for enhancing the game. The games which have the highest number of 3D printing models created are shown in Figure 3 for both aforementioned geeklists.

We can see that in terms of generic 3D models, 'Catan' (originally 'Settlers of Catan') is the game with the highest number of models (the highest entry is for miscellaneous game accessories, such as life counters, markers, etc, and thus not for a particular game). In Figure 3a we can see that the second

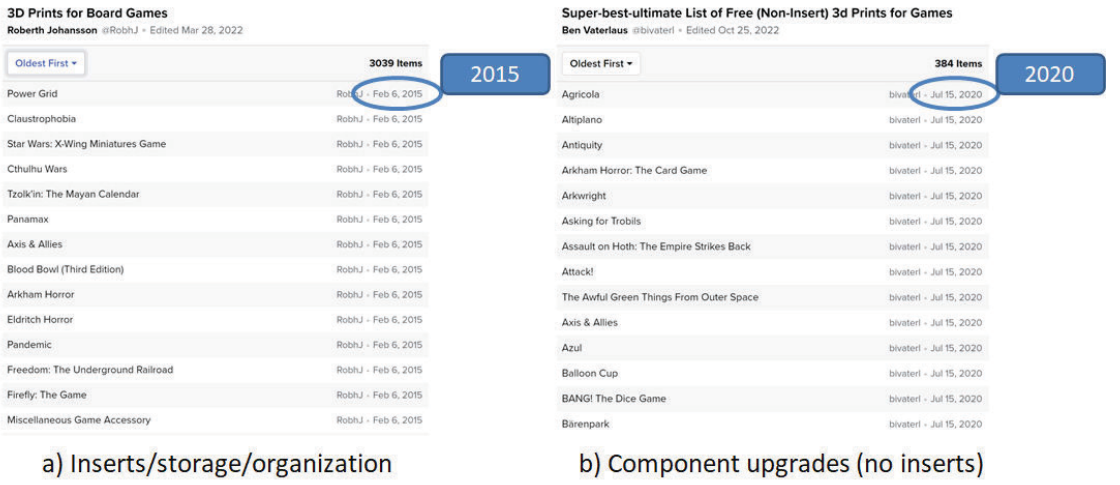


Figure 2
(a) earlier entries of the geeklist on 3D components for board games including inserts, and (b) the same for the geeklist that excludes inserts.

highest models game has less than half of 'Catan' and is 'Star Wars: X-Wing', with then a large number of games with almost the same number of components. This Figure also shows the current BGG ranking of each game, and it is curious that there are only 2 top 100 entries in the list of games with highest number of 3D models being shared. In Figure 3b we see the number of models by year, meaning, the number of models shared per year since launch (number of models divided by the age of the game). Some games in this list are very recent and thus rank very high. A good example is 'Dune: Imperium', a game from 2020 with already 8 entries (roughly 2.7 models per year). Here, one notices very clearly how the games for which there have been more frequent contributions are not necessarily high in the global BGG rank, with only 1 top 100, 1 top 200, and a total of only 6 in top 1000.

In Figure 4, we observe the same information but now excluding inserts/storage 3D models. In this case, 'Star Wars: X-Wing' is by far the game with more enhancement contributions, almost twice that of 'Terraforming Mars', the second entry. Curiously 'Dune: Imperium' is featured here also, highlighting how for this game there are contributions both related to storage and to game components (looking at those models we find mainly upgraded tokens for resources and score markers). If we look at the list in terms of 3D models released per year for each game, the distribution is much more similar than it was for the generic geeklist (from Figure 3), with a lot of games from Figure 4a again featured in Figure 4b, such as 'Star Wars: X-Wing miniatures', 'Dune Imperium', 'Spirit Island', 'Terraforming Mars', 'Dice Throne', 'Eldritch horror', 'Dinosaur Island', 'Nemesis', or 'Wingspan'.

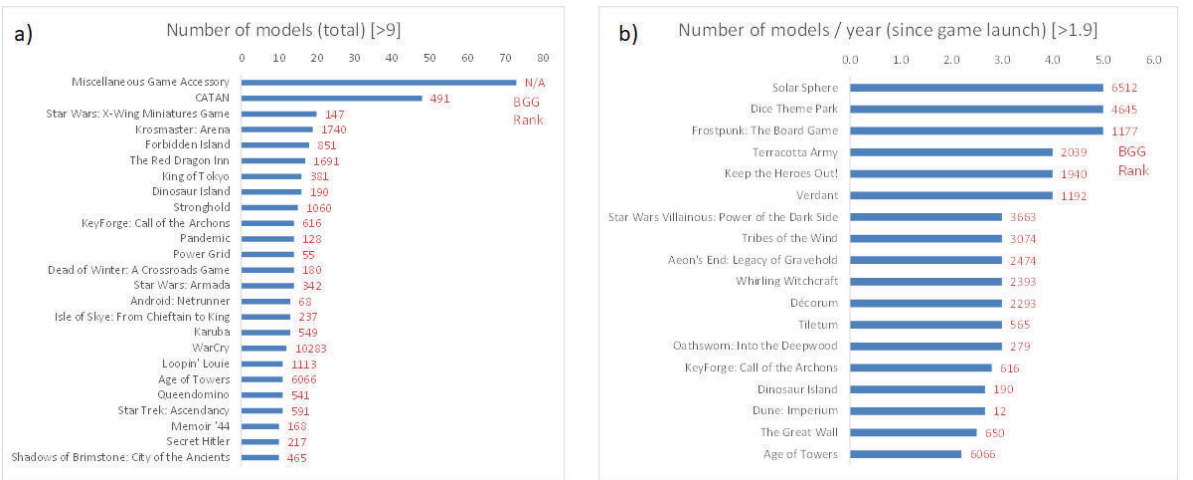


Figure 3
(a) games with the highest number of entries in the geeklist of 3D components for board games including inserts (only games with more than 9 entries), and (b) games with highest number of 3D models per year. In both cases, the current BGG global rank is listed for each game.

From the perspective of designers and publishers, a couple of examples showcase how 3D printing is already changing the industry:

- The "HE.R.O.: The pandemic" expansion is available in the form of STL files, for players to print themselves, through the online shop "eelyriver". The description of this item is "Upgrade your board game experience! You receive the STL-Files for all the miniatures of HE.R.O The Pandemic expansion. You will need to print them yourself with a 3D-printer". As a minor expansion, the publisher chose this means of making it available to the public.
- The "Aldarra" kickstarter includes in pledges of US$25 (or higher) the STL set of components, which means players receive the STL files of the game components which they can print themselves.

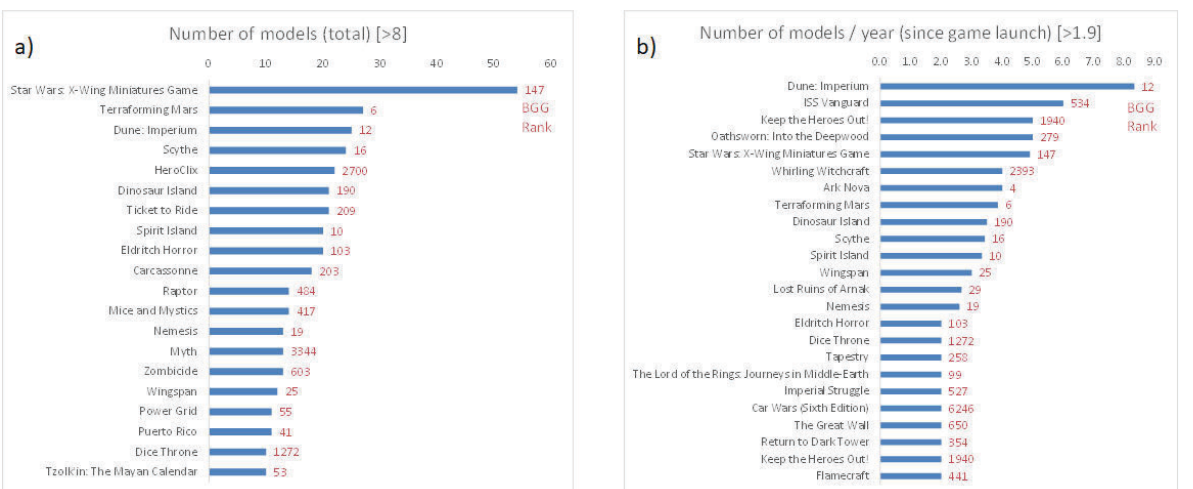


Figure 4
(a) games with the highest number of entries in the geeklist of 3D components for board games including inserts (only games with more than 9 entries), and (b) games with highest number of 3D models per year. In both cases, the current BGG global rank is listed for each game.

a b c d

Figure 5
Examples of 3D models for some top rated board games: (a) insert for Mage Knight Ultimate Edition designed by Thogra (obtained from Thingiverse, id number 4769225); (b) player mat overlay for Terraforming Mars designed by Kovirek and printed by Wahngrok (obtained from Thingiverse, id number 3976849); (c) Sojourner Probe Model for Terraforming Mars designed by gryn (obtained from Thingiverse, id number 2720390); (d) first player marker for Dune Imperium designed by Dominion6Studios and printed by greendog99 (obtained from Thingiverse, id number 4721055).

## Future opportunities for 3D printing in board games

With 3D printing's ubiquitous growth, combined with decreasing costs and more widespread availability, it is expected that many opportunities will appear to take advantage of the potential of 3D printing in the board games industry. In particular, delocalized 3D printing allows for a wider range of market options for game designers / publishers, among which some high potential features include:

- Feasibility of making available a deluxe version (which might be deemed a too small production run to justify mass market), by releasing upgraded/improved content tailored for each gamer. E.g. a player might only want deluxe character pieces but not new cards or new dice.
- Easier release and distribution of expansions, which in many cases, only include added parts without replacing others of the base game (e.g. a board or cards).
- Promoting customization by players (which is detailed further below).
- For some miniatures-heavy game, planning for end-user 3D printing could allow reducing base game and shipping costs, by shipping with fewer core components, allowing some 3D components to be printed as the player wants, following some of the principles of Print'n'Play (PnP) with paper.

If we tackle in more detail the aspect of customization by players, it is possible to envision several venues for publishers to accommodate and foster this:

- Allowing a player to try out the game with simple, e.g. cardboard pieces, and upgrading to more advanced versions depending on how much they want to invest in the game. There are some kickstarter pledges already featuring this approach, but it is not at all used in retail versions of board games.
- Enabling players to only produce the number of parts they need, e.g. depending on the number of players involved. In many games, the retail version of the game includes components for up to 4 players, but some clients might never play the game with more than 2, and it would thus be pos-

sible to distribute 2-player versions of the game for those who wanted such option (although obvious logistic limitations can easily be brought up).
- Allowing multiple alternative design/art for the same parts, e.g. male vs female versions, multiple boat sizes and/or shapes, etc.

In the same way, 3D printing opens up several interesting opportunities for game designers, in addition to those previously mentioned:

- Rapidly modifying game elements/components during early design. This type of agile operation, with changes that can be implemented essentially overnight, gives a huge advantage to a designer. Traditionally, new components would have to be ordered from a manufacturer, or at the very least, proxies would have to be sought after in local stores. With 3D printing, as soon as a team meeting ends with agreed changes, new components can start printing.
- Beta testing different components (shapes, sizes, material, geometric complexity). This creates a fantastic opportunity for creativity. If a designer is struggling whether to order character miniatures of a smaller or larger size, or whether they should include weapons in a certain position, each option can be quickly 3D printed and validated by actually having the part on the table rather than just sketches or a proxy part. And since more games keep including geometrically intricate components (such as ships, characters, or objects), having accurate versions at the beta-testing ensures more reliability from feedback at this stage.
- Validate table 'presence' of the game and player interaction by using physical components which are closer to what is expected in the release version. It is entirely different to test how a game looks on a table from a cardboard early-design board to having a production-standard setup on the same table. By having players sit at a realistic version of how the game will look in the production run, nuances of how players engage with components become clearer and, thus, more informative.
- Use complex shapes for some components that would be unfeasible through traditional fabrication methods. If a game aims to have a unique promo, a starting player token, or an effect marker that stand out, designers can take advantage of 3D printing capabilities to produce extremely complex geometries that traditional fabrication techniques would be unable to produce or would require several sub-components glued or welded together. Less important than the other aspects previously mentioned, a particular shape might have a strong visual impact on a certain game.

## Concluding remarks

As was shown, 3D printing is already a widely used technology in the context of modern board games. However, its use is currently still almost exclusively in the hands of hobbyists in a DIY setting. These hobbyists have been creating and sharing 3D models online for several years, in an ad-hoc approach as required by their own need to upgrade/enhance their games. This type of open community actually fosters creativity and, in some cases, leads to inclusive solutions, providing a wider range of people with the possibility to play modern board games.

It is already possible to find kickstarter/gamefound examples using 3D printing to either provide players with the possibility to print components they lost or destroyed, or producing a

set of new characters for a mini-expansion of a game which is not aimed at retail market and will never be distributed worldwide in a traditional manner. These types of initiatives show multiple options for the future, some of which the board games industry might want to adopt.

As 3D printing can be an important tool for game designers/developers, publishers can use it to involve the players, allowing them to intervene in the process (delocalized production, guided customization, etc). And if this is done with proper planning, efficient use of resources, and adequate care for end-of-life, it can contribute to a more sustainable future.

Despite these positive remarks about the use of 3D printing for modern board games, it should be mentioned that 3D printing is not a technology as mature as paper printing. It still requires expertise, can lead to frustration for casual hobbyists, printers require maintenance and care, and creating new models requires specialized software and skills. And while it can address producing many different types of components, from miniatures to tokens and organizers, it does not cover all components of a game, such as a board or character sheets.

Also, although this paper is focused on 3D printing, there are other technologies with great potential for improvement and customization of board games, and laser cutting should be mentioned. Laser cutting is extremely accurate but has 2 major disadvantages: the entry cost of equipment (even the most basic) is much higher than 3D printers, and it works only in planar (two dimensional) geometries. Thus, laser cutting is particularly useful, and has been widely used, for player mats and storage boxes (these are usually made of wood/MDF and require cutting several 2D geometries and assemble them into 3D boxes).

In any case, improved customization is incompatible with standardized mass production, so 3D printing will continue to play a vital role and its importance in modern board games should increase as the technology becomes continuously more accessible (in terms of costs and easy access to a printer). There are clearly many opportunities in this growing market, and it is worth considering how best take advantage of it, for all parties involved.

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